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Detection of Soil Erosion with Thematic Mapper (TM) Satellite Data within Pinyon-Juniper Woodlands

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Prepared by

Kevin Paul Price

Center for Remote Sensing and Cartography
University of Utah Research Institute
391-D Chipeta Way
Salt Lake City, Utah 84108

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ABSTRACT

Pinyon-juniper woodlands dominate approximately 24.3 million hectares (60 million acres) in the western United States. It is estimated that 50% of the lands now occupied have been invaded in the last 125 years.

The overall objective of this study was to test the sensitivity of Landsat Thematic Mapper (TM) spectral data for detecting varying degrees of soil erosion within the pinyon-juniper (*Pinus edulis* and *Juniperus osteosperma*) woodlands. A second objective was to assess the potential of the spectral data for assigning the Universal Soil Loss Equation (USLE) crop management (C) factor values to varying cover types within the woodland.

Thematic Mapper digital data for June 2, 1984 were used in the study. Spectral channels 2, 3, 4, and 5 were used in the analysis. Digital data analysis was performed using the ELAS software package developed by NASA's Earth Resource Laboratory (ERL). Best results were achieved using CLUS, an unsupervised clustering algorithm. Of the 169 spectral signatures generated, 40 were associated with the pinyon-juniper cover types. Fifteen of the 40 pinyon-juniper signatures were identified as being relatively pure pinyon-juniper woodland. Final analysis resulted in the grouping of the 15 signatures into three major groups. Ten study sites were selected from each of the three groups and located on the ground. At each site the following field measurements were taken: percent tree canopy and percent understory cover, soil texture, total soil loss, and soil erosion rate estimates. A technique for measuring soil erosion within pinyon-juniper woodlands was developed. A theoretical model of site degradation after pinyon-juniper invasion is presented.

Results show greatly accelerated rates of soil erosion on the pinyon-juniper sites studied. Percent cover by pinyon-juniper and the soil loss estimate accounted for 68% ($R = 0.820$) of the variability in TM satellite channel 4. When estimates of soil loss were used as the dependent variable in multiple regression analysis, TM channel 5 was found to explain more variability in soil erosion than all other field factors combined. Satellite data were found to be more sensitive to vegetation variation than the USLE (C) factor coefficients. It was concluded that satellite data can be used to assign reliable USLE (C) factors to cover types within pinyon-juniper woodlands, though USLE was found to be a poor predictor of soil loss in those woodlands. It is recommended that a new erosion model be developed which integrates satellite spectral and digital elevation data for use on pinyon-juniper woodlands.

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ACKNOWLEDGMENTS

I wish to express my appreciation to the USDA Soil Conservation Service (SCS) and National Aeronautic and Space Administration (NASA) for funding provided to conduct this study. Also, assistance and council provided by the personnel at the State Office of the SCS was greatly appreciated.

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INTRODUCTION

Eleven species of pinyon and nine species of juniper trees are native to the semiarid regions of the western United States. These trees are the dominant plants on approximately 24.3 million hectares (60 million acres) (West 1984).

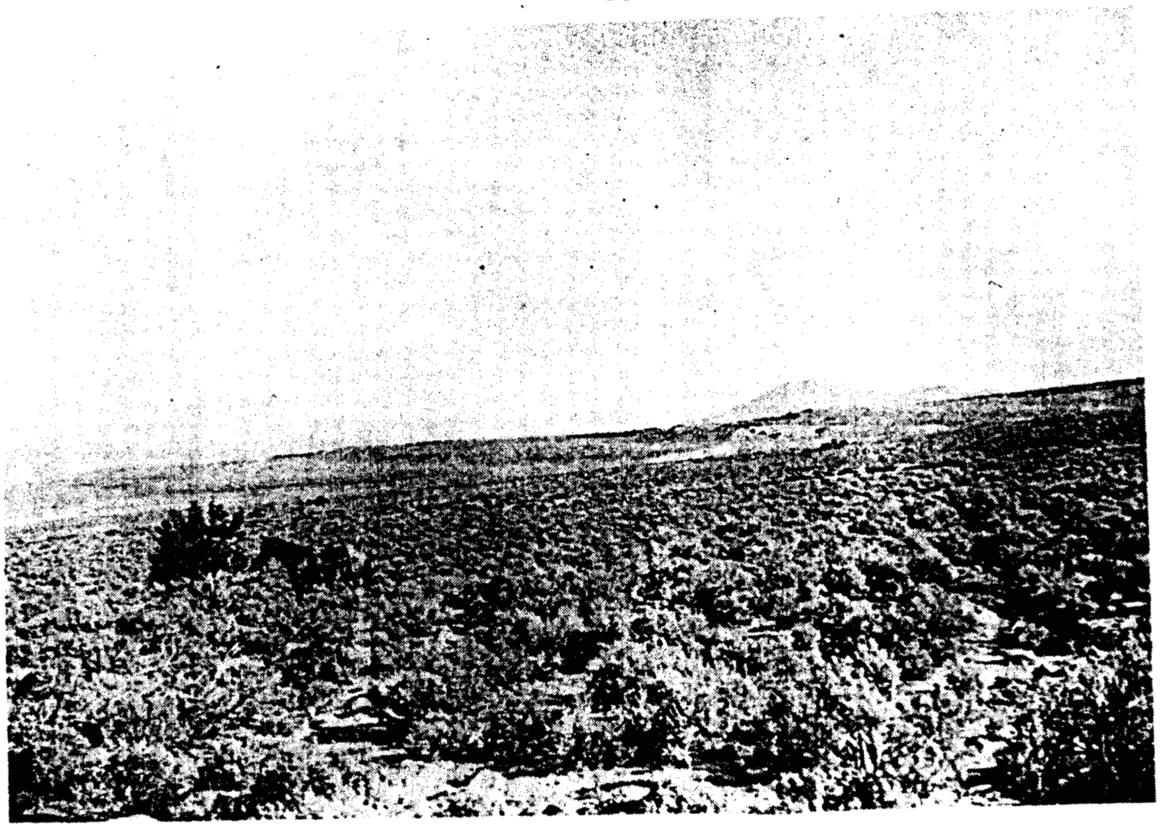
Common to the state of Utah are single and double needle pinyon pine (*Pinus monophylla* Torr. and Frem., and *P. edulis* Engel., respectively) and Utah juniper (*Juniperus osteosperma* Torr.). Pinyon-juniper vegetation occurs in an altitudinal belt from about 975 m (3,200 ft) to 2,560 m (8,400 ft). This zone receives an average annual precipitation of 25.4-38.1 cm (10-15 in) (Woodbury 1947). Although the lower elevation limit for pinyon-juniper is apparently set by deficient precipitation, studies suggest that colder temperatures and variable soil characteristics determine the upper elevation limit (Brotherson and Osayande 1980; Howell 1941; Larson 1930; Tueller, Beeson, Tausch, West, and Rea 1979; West, Tausch, Rea, and Tueller 1978; Woodbury 1947; Woodward, Harper, and Tiedemann 1984).

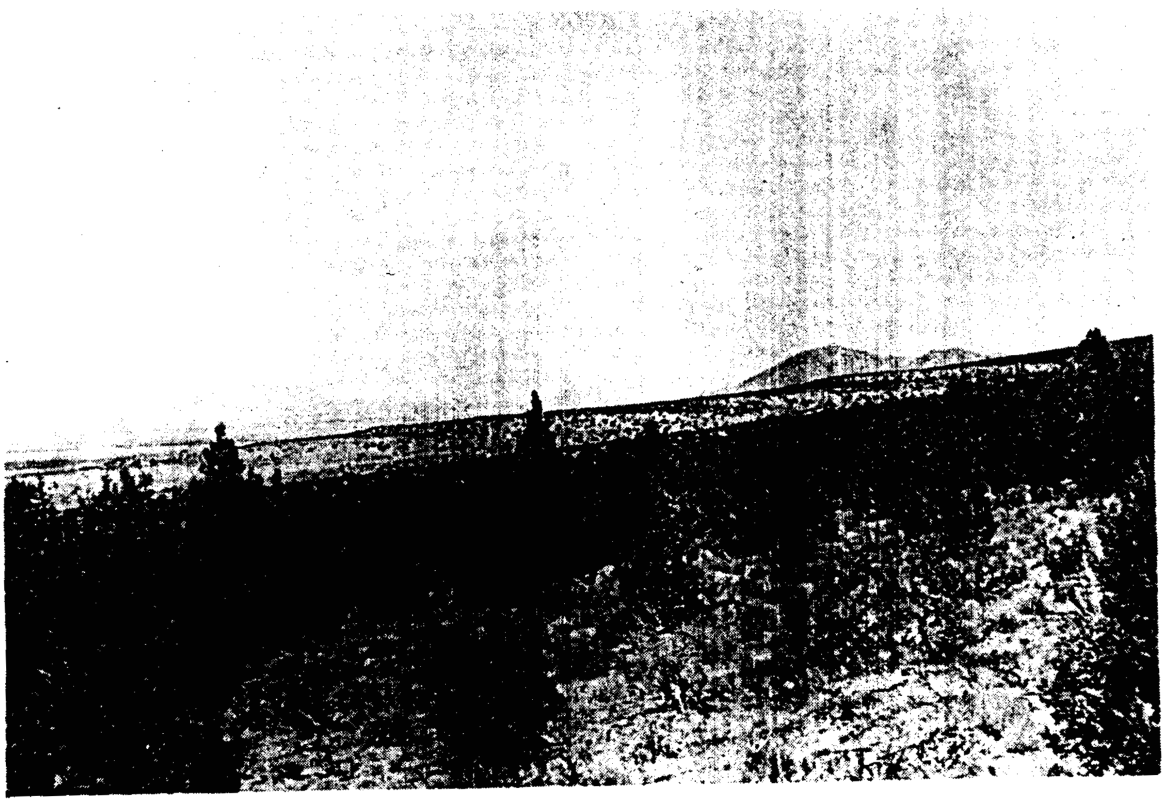
Since the mid-1800s, this vegetation type has greatly increased in area and density (Rogers 1982; Tausch, West, and Nabi 1981; West 1984). The invasion has extended onto lower elevation western rangelands which were previously occupied by perennial grasses and sagebrush. Figure 1 is taken from Rogers (1982) (Reprint with permission form University of Utah Press). The photographs show a progressive invasion of pinyon-juniper invasion between the years 1901 and 1976. Tausch et al. (1981) estimate that about 50% of the lands now dominated by pinyon-juniper, have been invaded in the last 125 years. Prior to nineteenth century settlement of the western United States, pinyon and juniper (particularly

FIGURE 1. Photographs of Stansbury Mountains, Utah.

a. Photograph taken in 1901. The dominant plant at this time was big sagebrush (*Artemisia tridentata*).

b. The match photograph to Figure 1a taken in 1976. The dominant plantis now Utah juniper (*Juniperus osteosperma*). These photographs show a dramatic change in vegetation type in only a 75-year period. (Photographs taken from Rogers, 1982. Reprinted with permission from University of Utah Press).





juniper) were confined to sites characterized by slopes of greater than 25% and soils with greater than 15% rock cover (Sauerwein 1981). As a result of this invasion, valuable natural resources have been lost. Losses are attributed primarily to accelerated soil erosion and competitive exclusion of desirable forage species. The resource losses associated with pinyon-juniper invasion have prompted research on type conversion at selected sites throughout the western United States.

This study investigates the use of Thematic Mapper (TM) satellite digital data to assess variations of soil loss within pinyon-juniper woodlands. The sensitivity of satellite spectral data to variations in pinyon-juniper cover is also investigated.

Study Purpose and Objectives

The purpose of this study is to assess the utility of TM digital satellite data in an area presently dominated by pinyon-juniper trees. Assessments were made for the following procedures:

1. determination of the sensitivity of TM satellite data to varying conditions of soil erosion within the pinyon-juniper woodland type, and
2. testing the utility of Landsat TM data for assigning the Universal Soil Loss Equation (USLE) crop management (C) factor to various cover types within pinyon-juniper woodlands.

To the extent the endeavors of this study are successful, the following objectives will be realized:

1. improvement of existing techniques used for identifying land units that have accelerated soil erosion,
2. improved objectivity and greater economy in field data collection,

3. greater information availability for land managers establishing a Geographic Information System (GIS).

Statement of Hypotheses

1. Landsat IV TM satellite digital data can be used to detect varying degrees of soil erosion within the pinyon-juniper community type.
2. Landsat IV TM satellite digital data can be used in pinyon-juniper woodlands to assign soil erosion indices for use in soil erosion prediction models. More specifically, TM data can be used to assign the cover management (C) factors for use with the USLE.

DISCUSSION OF LITERATURE

Pinyon-Juniper Management Issues

Management Strategies

A number of hypotheses have been advanced to explain the apparent accelerated rate of pinyon-juniper spread in western United States. Among the more often stated explanations are 1) removal of natural plant competition by livestock overgrazing, 2) reduction of wildfires, 3) climatic change, and 4) reinvasion of sites cleared of trees by nineteenth century settlers (West 1984). Most likely, varying combinations of all of the above are responsible for the spread of this woodland type.

An historical review of the literature indicates that there has been continual controversy over appropriate usage of, and management practices in the pinyon-juniper vegetation type. Early resource managers regarded the trees as weeds needing to be eradicated to improve range forage quality. In recent years, the adoption of multiple-use management objectives has greatly slowed tree eradication programs which were common during the 1950s and 60s.

Over the years, many ideas have been proposed for proper management of pinyon-juniper woodlands. Recent increases in fossil fuel prices have promoted the study of fuelwood production from pinyon-juniper woodlands (Young and Budy 1987). Tidwell (1987) concludes that sustained yields of pinyon-juniper woodlands are important in providing such resources as: firewood, fence posts, specialty wood products, chips, Christmas trees, pinenuts, wildlife habitat, livestock forage, wild horse and burro habitat, watershed stability, and public recreation.

The change in pinyon-juniper management objectives has precipitated a philosophical polarization of some rangeland ecologists and resource managers. There are some who question the wisdom of pinyon-juniper eradication practices (Clary, Baker, O'Connell, Johnsen, and Campbell 1974; Gifford 1987). On the other hand, there are others who are concerned that pinyon-juniper invasion promotes site degradation (Bedell 1987; Doughty 1987; Renard 1987; Sauerwein 1984; Tausch 1980; and West 1984). A probable reason for the theoretical differences of opinion is the lack of data to substantiate either side of the issue. Quoting from West (1984, p. 1313-1314), "It should be emphasized that there is no definitive proof that erosion rates have increased with tree dominance since no before and after data on the same sites exist. Furthermore, we have no erosion data from relict areas."

A reason for the lack of erosion data on pinyon-juniper sites is the lack of methods for estimating rate of soil loss on pinyon-juniper woodlands. Past erosion models have been developed on agricultural lands and are not well adapted to rangelands. According to Abel and Stocking (1987, p. 460),

> Soil erosion is normally cited as a contributory process, but estimates of its rate on rangeland are scarce. This is not, we suggest, because such estimates are considered unimportant, but because technically feasible, cost-effective methods have yet to be developed for rangelands.

There are a few studies which describe techniques for estimating erosion rates on pinyon-juniper woodlands. A study conducted by Carrara and Carroll (1979) reports the use of exposed tree roots and tree ring analysis to obtain direct estimates of soil erosion rates in the pinyon-juniper woodlands of Colorado. McCord (1987) also discusses the use of exposed tree root and tree ring analysis to estimate sediment loss from "Dead Juniper Wash" a tributary of Dinnebito Wash on Black Mesa in Arizona. In McCord's study, juniper trees were estimated to be approximately 650 years old.

The exposed root/tree ring analysis technique was considered for this study, but field observations in the study area revealed that within the relatively young pinyon-juniper stands (approximately 80 - 90 years), no roots were exposed. Within the study area, erosion tracks were often deep enough to expose fine roots, but under trees soils were protected from erosion by canopy cover and the accumulation of several inches of foliar needles and scales. The question also arose concerning the effect accumulation of canopy litter would have on the erosion estimate. Personal field observation suggested a significant reduction in soil erosion under pinyon-juniper canopy due to the accumulation of tree residue on the ground. It is also believed that the tree root exposure/tree ring analysis method would significantly underestimate soil loss because the technique fails to account for the increased soil erosion between the trees.

Theoretical Model of Site Retrogression

Results from several studies indicate that reclamation of sites invaded by pinyon-juniper yielded insignificant benefits in terms of soil stability (Clary et al. 1974; Gifford, Williams, and Coltharp 1970). Nevertheless, it seems doubtful that existing studies provide sufficiently conclusive data to justify recent changes in pinyon-juniper management guidelines. This is especially true when one considers ways in which their study results may have been misinterpreted.

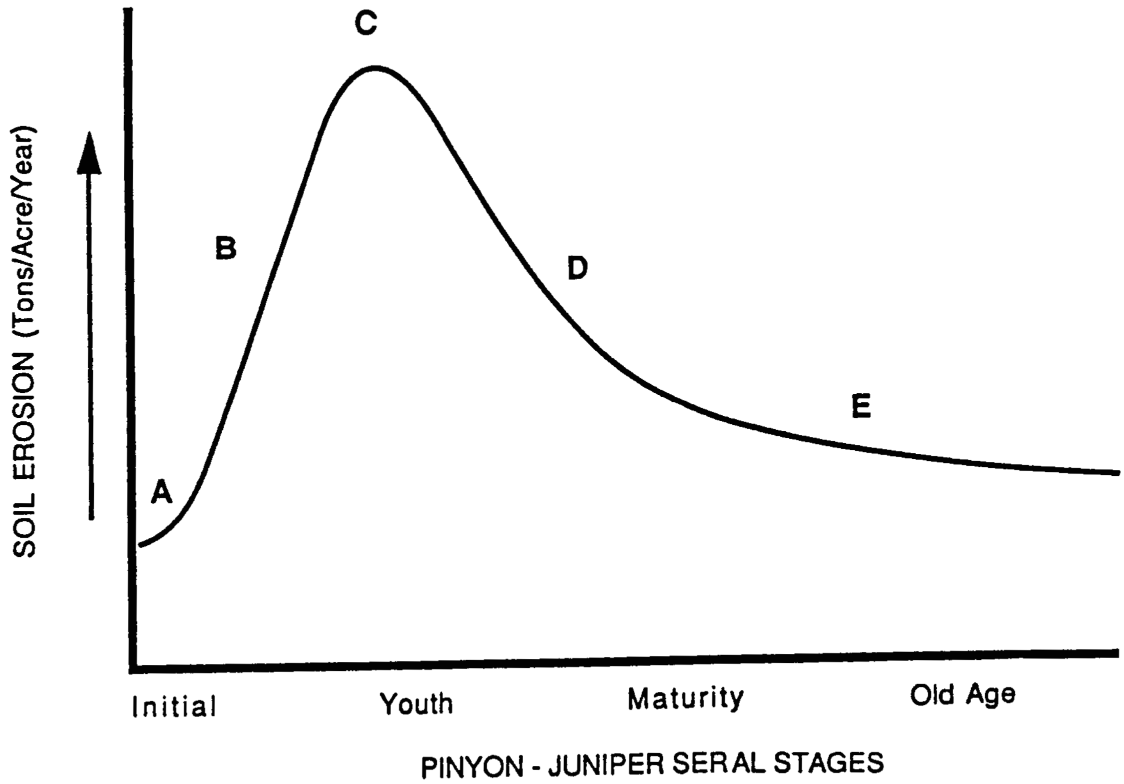
Although stand age on control sites was not reported in the studies by Clary et al. (1974) or Gifford et al. (1970), I assume based on their comments and photos that sediment measurements were extracted primarily from mature, well established stands of pinyon and juniper. If this assumption is correct, it is not surprising that no significant differences in sediment yields were found between "treated" and "untreated" pinyon-juniper sites.

Although little actual data exist to substantiate my position, I postulate that the majority of soil erosion on pinyon-juniper sites occurs within a relatively short time after initial invasion. This theory is based primarily on personal field observations and the results of this study. While traversing the sagebrush/ pinyon-juniper ecotone, one often observes differences in site stability between the two vegetation types. Differences are usually noticed in soil characteristics such as percent soil surface covered by rock and gravel, soil structure, and soil texture. Newly invaded sites also show signs of increased sheet, rill and gully erosion. There is usually evidence of accelerated understory dieoff, and soil pedestalling is common, with some observations of perennial grasses atop soil pedestals 10.2-15.2 cm (4-6 in) high.

There are research findings to support the above statement. Clary (1987) cites several studies which document dramatic reductions in herbage production with as little as 10% tree canopy cover (Arnold, Jameson, and Reid 1964; Clary et al. 1974; Jameson 1967; Short, Evans, and Boeker 1977; Tausch et al. 1981). Young (1984) reported that in the early stages of invasion of a Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingenesis*) site, juniper density was doubling every three years. If reduction of understory plants contributes to increased soil erosion, the above studies would support the belief that invasion by pinyon-juniper increases soil erosion.

Figure 2 graphically illustrates my hypothesis of how soil erosion is related to time after an invasion by pinyon-juniper vegetation begins. The alpha characters, A-E, reference the various stages of site stability which are associated with pinyon-juniper stand development. The beginning of the curve represents erosion from a site at time of "initial" invasion by pinyon-juniper. Note how rate of erosion changes as the pinyon-juniper stand progresses through the

FIGURE 2. Graph depicting theoretical seral stages of pinyon-juniper woodland development and soil erosion associated with each stage.



C
B
D
E
A
SOIL EROSION (Tons/Acre/Year)
Initial
Youth
Maturity
Old Age
PINYON - JUNIPER SERAL STAGES

developmental stages of "youth," "maturity," and "old age." Point "A" on the graph represents a system which experiences little accelerated erosion. (If the system were not ecologically out of balance, it probably would not be susceptible to invasion.) At point "B," system equilibrium is further upset due to increased invasion of pinyon-juniper. At this stage, there is a rapid depletion of understory and top soil is eroded from the site at an accelerated rate. At point "C," rock debris exposed by eroding soils begins to retard soil movement. The "D" stage is a gradual deceleration of erosion resulting from increased surface rock material. Simanton, Rawitz, and Shirley (1984) show that there is an exponential relationship between rock fragments covering the soil surface and soil erosion. It should be noted that erosion rates are dependent upon soil types. Soils with little rock material may continue to erode at an accelerated rate for a much longer period. The "E" stage is reached when a new equilibrium is established in the system and soil loss is moderated by exposed surface rock material and increasing cover of pinyon-juniper canopy and litter. Stabilization may also be retarded if erosion exposes a massive soil clay layer, a mineral hardpan, or bedrock.

If this hypothesis is valid, it would suggest that measurements of sediment losses from mature pinyon-juniper stands (stage E) would show similar losses to those for initial invasion or preinvasion conditions (stage A). Study results for erosion measurements collected only at stages (A) and (E) would lead one to believe that pinyon-juniper invasion has little effect on soil stability. If one were to compute the economics of reclamation on sites already severely deteriorated, it would be difficult to justify reclamation work, but if one begins at the "initial" invasion stage, and accounts for losses and damages incurred through the "maturity" stage, it is likely that the results would favor suppression of pinyon-juniper invasions onto lower elevation lands. Studies to evaluate the economics of pinyon-juniper reclamation should consider the costs of soil and other resource losses associated with entire successional sequences from initiation of pinyon-juniper invasion to maturation of the woodlands. Examples of other resource losses would include such off-site factors as river system degradation and reduction of reservoir holding capacity.

Since some land managers favor sustained yield of pinyon-juniper for its fuelwoods, fence posts, Christmas trees, etc. (Tidwell 1987), a question that must be addressed is how long will rangeland soils continue to sustain production? Tiedemann (1987) suggests that the removal of large quantities of tree biomass could deplete soil nutrients. Assuming this to be true, once nutrients have been depleted one could expect sites to support only sparsely vegetated woodlands.

If the end result of sustained yield of pinyon-juniper woodlands is increased exposure of soil surfaces, land managers have reason for concern over further desertification on western rangelands. Since no one can predict the outcome, studies must be conducted to evaluate environmental trends associated with invasion of rangelands by pinyon-juniper trees. Once environmental trends are documented, and soil erosion rates established, better estimates for cost comparison studies can be obtained and the controversy over pinyon-juniper management objectives resolved.

Soil Conservation Service Erosion Concerns

Managers of the United States Department of Agriculture, Soil Conservation Service (SCS) are vitally concerned with soil erosion. In the past, they have been responsible for assisting agriculturalists with erosion problems. Rangeland scientists at the Utah SCS State Office consider that lands occupied by pinyon-juniper vegetation are susceptible to accelerated soil erosion. Potential resource losses associated with pinyon-juniper invasion have prompted SCS personnel to recommend research and pinyon-juniper control on selected sites.

Recognizing the large area occupied by pinyon-juniper woodlands, some personnel at the SCS consider that the problem of inventory and monitoring of the woodland can be done most economically and reliably with remotely sensed data. It is hoped that satellite data, coupled with topographic, precipitation, and soils information, can be used to delineate vegetational units that vary in respect to the potential for soil erosion.

The SCS and NASA have supported the research reported in this dissertation. Believing that much will be gained by using satellite data in resource management, the Utah State Office of the SCS has assumed a leading role in investigating the use of satellite imagery for analysis of pinyon-juniper environments in the western United States.

Resource Management Using Satellite Information

Future of Remote Sensing

The responsibility of managing 24.3 million hectares of dynamic woodland is a daunting task, especially at a time when the budget of resource managers is stretched farther than at any time in the recent past. For this reason, some resource managers are looking to satellite remote sensing technology to provide information otherwise impractical or impossible to obtain.

Since World War II, when remote sensing came into use, great progress has been made in spectral sensing technology and analytical procedures. The July 23, 1972 launching of the first Landsat satellite opened a new era in earth study. The continual improvement of remotely sensed data has made such information increasingly useful to resource analysts in many fields. In the past 15 years, improvements have been made in nearly every aspect of remote sensing. Available now are many kinds of remotely sensed information, such as black and white and color infrared aerial photography. Data in visible, near infrared, middle infrared, thermal infrared, radar, microwave, laser, and other spectral forms are available in image and digital form. Not only has data variety increased, but the quality of information has greatly improved with respect to the spectral, spatial, and radiometric resolution.

The future of resource management will be significantly influenced by remote sensing technology. In the 1990s the development of a new manned low-altitude orbiting space station offers exciting possibilities to land managers. By the mid 1990s, near real time remotely sensed spectral data of the earth should be available to natural resource managers. Tueller (1987, p. 240) discusses future resource management methods which will utilize real-time spectral data,

> Last year President Reagan announced that the design and development of a space station will proceed. Such space stations will eventually become permanent observation platforms in space. Observations will be made to understand the dynamic physical, chemical, and biogeochemical processes on the earth and to make this information readily available to managers back on the earth (Frost and McDonald 1984). One can easily visualize the manager of a stand of pinyon-juniper requesting certain kinds of information from scientists manning the space station and getting data in a matter of hours upon which a management decision can be based.
>
> A future manager of pinyon-juniper woodlands might well receive over 75 percent of the information required for management from a series of sensors carried on board either an orbiting satellite or space station.

To the environmental researcher, remote sensing data provides another great benefit. Satellite spectral data are in raster (matrix) format, which provides a perfect data input into a Geographic Information System (GIS). In recent years, computer and software improvements have made it possible to simultaneously analyze vast areas and layers of spatial information. The ability to do environmental modelling using a GIS data base will soon be considered an essential skill for conducting state-of-the-art environmental research.

Natural Resource Management from Space

The literature shows that remote sensing is commonly used to monitor and study agricultural crops. Geologists commonly use the information to map rock formations, study geologic structures, or explore for mineral and/or hydrocarbon deposits.

Forest managers also depend heavily on remote sensing data. Peterson, Westman, Stephenson, Ambrosia, Brass, and Spanner (1986) used Thematic Mapper (TM) Simulator data to analyze forest structure in the Sequoia National Park. Nelson, Krabill, and Maclean (1984) are studying the use of airborne laser data for determining differences in forest canopy characteristics. Remote sensing for vegetation analysis is most commonly used in areas of the world where vegetation is plentiful. Less research involving satellite spectral data is apparently in progress on arid or semiarid lands. This is probably related to greater difficulty associated with geographic diversity and sparse vegetation common on rangelands. More recently, world attention to human starvation in aridlands has created greater interest in aridland ecosystems. Funding for studies dealing with the issues of global habitability has increased. Satellite data can be expected to greatly assist scientists involved in global research. Concern over desertification in semiarid regions of the world has prompted investigation of satellite spectral information for monitoring of environmental degradation. In response to this concern, Walker and Robinove (1981) published an annotated bibliography on remote sensing methods for monitoring desertification. Tucker, Vanpraet, Boerwinkel, and Gaston (1983) are using the Advanced Very High Resolution

Radiometer (AVHRR) NOAA-7 satellite data for mapping vegetation on the African continent.

Remote sensing of rangelands. Research dealing with remote sensing of rangelands often involves mapping or monitoring of vegetation. Jaynes (1983) used Multispectral Spectral Scanner (MSS) digital data to accurately map range types on the Parker Mountain, Utah State Land Block. The predominant vegetation type of the Parker Mountains is big sagebrush (Artemisia tridentata) and quaking aspen (Populus tremuloides). Jaynes was successful in accurately (89% or better) delineating subtle variations (i.e., shrub height, shrub species) within both community types. McGraw and Tueller (1983) also used MSS data to map big sagebrush in northern Nevada. Other plant community types that they were successful in correctly classifying were brush, mountain shrub/juniper, conifer, and meadows. Price, Ridd, and Merola (1985) were successful in accurately mapping mixed desert saltbush types in Rush Valley, Utah. Their classification accuracy was improved by 20% when ancillary information was used to augment the spectral data.

Ustin, Adams, Elvidge, Rejmanek, Rock, Smith, Thomas, and Woodward (1986) used Thematic Mapper (TM) data to study semiarid shrub communities in Owens Valley, California. They report the use of a variety of analytical methods and discuss information about the environment made apparent through remotely sensed data. Spectral data are also being used with varying degrees of success to estimate phytomass. Harlan, Boyd, Clark, Clarke, and Jenkins (1979) report good success in using vegetation indices to estimate phytomass production in a semiarid environment.

Spectral data are also used to monitor rangeland change. Robinove, Chavez, Gehring, and Holmgren (1981) used albedo differencing to produce a map of environmental change on rangelands at the Desert Range Experiment Station in Pine Valley, Utah. They postulated that an increase in albedo, on desert rangeland, is usually indicative of an area undergoing desertification. Frank (1984) used Landsat residual images to assess changes in surficial characters in a semiarid environment near Price, Utah. He found changes in albedo to be the most important indicator of vegetation change. He also found texture measurements helpful in improving his classification accuracy. Ramsey and Ridd (1987) report the influence of shrubs on the spectral signature in an aridland environment. Their findings indicate that as cover of shrubs increases, the brightness associated with the shrub site decreases. They attribute the spectral decrease to increased shadowing of the ground by shrubs. Graetz and Gentle (1982) used a saltbush community in Australia to model changes in the spectral signature associated with changes in solar altitude. Their results showed that differing amounts of shadow cast by different vegetation types could be useful in identification of those plant communities. Results from their model indicate that the best differentiation of community type was obtained using summer spectral data. Research to determine the effects of shadow on spectral signatures suggests that as vegetation changes from grass to shrub dominated cover there is a darkening of the spectral signature.

Musick (1984), and Warren and Hutchinson (1984) used multitemporal satellite data to assess environmental change on rangelands. They discuss variables that were identifiable from satellite and indicative of significant vegetational change. They also discuss methods for detection of vegetation change, results using different vegetation spectral indices, and methods for producing vegetation "difference" maps.

Satellite data for erosion monitoring. Numerous articles document the use of satellite data for monitoring of soil erosion. The majority of the studies assess the application of remote sensing techniques to erosion from agricultural lands. Much of the earlier remote sensing work was done by visual interpretation of the satellite image. As digital analysis techniques and spectral data have improved, the use of digital data for erosion assessment has increased.

Spanner (1983) used MSS data, coupled with Digital Elevation Model (DEM) data to derive USLE coefficients. His work was conducted in Ventura County, California, where he used satellite data to derive the vegetation cover (C) factor for mature orchard, immature orchard, row crops, river, urban, dense sod, chaparral, grass, oak woodland and barren. The DEM data were used to obtain estimates for slope steepness (S) and slope length (L) factors. A Geographic Information System data base was generated and annual soil loss was predicted for the study area. Estimates of erosion using this technique correlated well ($r = 0.91$) with manually derived USLE estimates. Stephens and Cihlar (1981) found Spot Simulator satellite data to give very accurate ($r = 0.97$) estimates for the USLE (C) factor on agricultural lands.

Satellite data for mapping pinyon-juniper. Tueller, Lorain, Halvorson, and Ratliff (1975) used ERTS-1 (Earth Resources Technology Satellite) to visually interpret natural vegetation in Nevada. The vegetation categories they used were: southern desert shrub, salt desert shrub, northern desert shrub, pinyon/juniper woodlands, mountain brush, aspen, meadows and marshlands, wheatgrass seedings, phreatophytes and cropland. Using summer imagery, they found it difficult to distinguish pinyon-juniper from areas with dark soils. They reported that winter scenes, taken at a time when snow was on the ground, were invaluable for mapping pinyon-juniper. Tueller et al. (1979) used Landsat-1 imagery to map pinyon-juniper in the Great Basin. Using satellite data, they estimate there are 7.1 million hectares (17.6 million acres) of the woodland type in the Great Basin. Todd, Gehring, and Haman (1980) used MSS digital data to map various densities of pinyon-juniper and shrubs in the Lake Mead National Recreation Area. To improve accuracy, they stratified pinyon-juniper cover into two major soil types, basalt and limestone derived. Elvidge and Lyon (1985) experimented with different vegetation indices on arid and semiarid lands. The vegetation types they examined were: pinyon pine, juniper, big sagebrush, bitterbrush, and desert peach. They found that soil and rock spectra can adversely affect the spectral signatures and create problems in correctly estimating green biomass. Their results showed that the most accurate estimates were made using the Perpendicular Vegetation Index (PVI), developed by Jackson (1983). Of the few studies addressing the use of satellite data in pinyon-juniper woodlands, none tested the use of spectral data as a source of information for examining variability in pinyon-juniper community structure. The literature search also revealed no studies which examine the use of spectral digital information for assessing soil erosion associated with pinyon-juniper woodlands.

Modelling Site Condition

Site condition, as it relates to this study, is a function of the major factors affecting the environmental stability of a geographic unit. Often, the most obvious evidence of site condition degradation is accelerated soil erosion. For this reason, considerable time has been spent in search of models and techniques designed to estimate soil loss.

Numerous models have been developed for purposes of estimating soil erosion and sediment yield. The models can be classified into three major types -

regression equation models, physical process simulation models, and stochastic (probabilistic) models. Some models are designed to estimate soil loss from large complex watersheds, while others are used to estimate erosion from single hillsides. Of the models investigated, some were so site specific that they were not applicable to other sites. Of the regression models available, the USLE seemed to be the most widely used model for predicting annual soil loss.

The application of the USLE to rangelands in the west has brought about much criticism. Many feel the equation needs to be modified to accurately model erosion associated with western rangelands. As a result, scientists are working to make improvements of the equation through the necessary modifications. One of the reasons USLE continues to be popular is because it is relatively easy to obtain values for the coefficients used in the equation. There are other models which may be more accurate in predicting erosion, but for the nonspecialist, correct derivation of the necessary coefficients is usually difficult. However, a recent article by Able and Stocking (1987) presents a soil erosion rate prediction model (Soil Loss Estimation Model for Southern Africa, SLEMSA) that has provided good estimates of soil loss on grasslands in Botswana. They claim the method to be rapid and relatively easy to use. As models such as the above continue to be developed and refined, estimates of soil loss on rangelands will improve.

Since most erosion information that the SCS has is based on USLE predictions, USLE field measurements were taken during this study for evaluation purposes. The following is a discussion on the pros and cons of the USLE developed by the National Runoff and Soil Loss Center of Purdue University, and the Modified USLE (MUSLE) proposed by Williams and Berndt (1976a).

Universal Soil Loss Equation

The widely used Universal Soil Loss Equation, developed primarily by Wischmeier and Smith (1978), is designed to predict sheet and rill erosion, and is most accurate when applied to single hillsides and small watersheds. The model was developed and tested east of the Rocky Mountains on agricultural lands. Recent work has extended its application to include range and forest lands (Wischmeier and Smith 1978). The USLE utilizes six major factors which are:

$$A = R * K * L * S * C * P$$

where:

A = predicted soil loss in tons/acre/year,

R = rainfall factor,

K = soil erodibility factor in tons/acre/year,

L = length of slope factor,

S = slope gradient factor,

C = crop management factor,

P = conservation practice factor.

Studies to evaluate the prediction accuracy of the USLE indicate significant error can result when the equation is applied to western rangelands (Gebhardt 1982; Hart 1984; Jensen 1983; Simons, Li and Associates 1982; Trieste and Gifford 1980; Williams and Berndt 1976a). As a result, much research to modify the factors for western lands has been, and is currently being, conducted.

The following references though not comprehensive, list persons who are or have recently been involved in studies dealing with USLE factors affecting soil erosion processes in the western United States.

(R) factor. Researchers who have investigated the rainfall (R) factor include Formanek, McCool, and Papendick (1984), Hart (1984), Hart and Loomis (1982), Jackson and Bondelid (1983), Johnson, Gordon, and Hanson (1984), Osborn and Lane (1969), Simanton and Renard (1982), Wischmeier and Smith (1978), and Zevenbergen (1985).

Of the six factors used in the equation, studies conducted on western soils show most prediction inaccuracies are a result of the rainfall (R) factor (Hart 1984; Osborn and Lane 1969; Simanton and Renard 1982; Simons; Li and Associates 1982; Trieste and Gifford 1980; Williams 1975). Unlike areas east of the Rockies, western rainfall comes as low frequency and high intensity thunderstorms. For this reason much work has been directed toward modelling the rainfall patterns characteristic of the west. As a result of this effort, Williams and Berndt (1976a) developed the Modified Universal Soil Loss Equation (MUSLE). This model will be discussed in more detail in a following section of this paper.

Research has also shown certain areas of the Pacific Northwest to be highly susceptible to soil erosion due to snowmelt and the actions of freezing and thawing (Formanek et al. 1984; Harr 1981; Harward, Kling, and Istok 1980; Johnson et al. 1984; Wischmeier and Smith 1978). Though certain areas in the West are very susceptible to snowmelt erosion, others are hardly affected. A three year study by Hart and Loomis (1982) indicates that erosion, due to snowmelt, along the Northern Wasatch Front is minimal. Their work estimates soil erosion from snowmelt to range between 3 and 26 lbs./acre/year.

(K) and (P) factors. The soil erodibility (K) factor has been studied by El-Swaify and Dangler (1976), Laflen (1982), and Wischmeier and Mannering (1969). Workers concerned with the conservation (P) factor include Adams (1966), Barnett, Diseker, and Richardson (1967), Carter and Carreker (1969), El-Swaify and Dangler (1976), and Foster (1982).

There seems to be less controversy regarding estimates of factors (K) and (P). Possible problems with (K) value estimates are discussed by Laflen (1982). His studies found the (K) factor, as calculated by Wischmeier and Mannering (1969), is in excellent agreement when compared with bench-mark soils. For rangeland analysis, the (P) factor is often assigned the constant value of 1.0. Nevertheless, Foster (1982) feels there is a need to properly consider effects due to ridges, steps, and cowtrails. In his opinion, the (P) factor should be adjusted to account for these effects.

(L) and (S) factors. The effect of topographic (L and S) factors on soil erosion has been studied by Foster and Wischmeier (1973), McCool (1982), Meyer, Foster, and Romkens (1975), and Williams and Berndt (1976b). Prediction inaccuracies commonly occur as a result of inappropriate slope length and slope gradient estimates. The USLE assumes slope shape to be uniform. Many slopes are not uniform, but vary from convex to concave or compound. Williams and Berndt (1976b) discuss techniques by which one can adjust for irregular slope shapes. They also discuss methods for more accurately determining slope length and gradient. Meyer, Foster, and Romkens (1975) and McCool (1982) discuss the influence of slope length, gradient and shape upon erosion processes.

(C) Factor. Workers who have evaluated the crop management (C) factor include Dissmeyer and Foster (1981), Jensen (1983), Warrington (1980), and Wischmeier (1975). According to Foster (1982), the cover management (C) factor is the single most important USLE coefficient. This factor is approximated using relationships between soil erosion and canopy, ground cover, soil consolidation, and plant roots (Wischmeier and Smith 1978). Data for these relationships were derived from studies describing the effects of straw, cornstalk, and stone mulches on processes of soil erosion. The tests were made on croplands, construction sites, and grasslands. Foster (1982, p. 97) states, "While the relationships have sound experimental bases and appear to give reasonable results, the derived (C) factor values have never been validated specifically for rangelands." Abel and Stocking (1987 p. 460) suggest a reason for the lack of erosion models designed for rangelands,

> One reason for the lack of development of methods for rangeland and the poor compatibility of existing methods for arable areas (e.g. Universal Soil Loss Equation, USLE: Wischmeier and Smith 1978) is the difficulty of estimating and interpreting the most influential variable in soil loss: vegetation cover.

On soils of the Caribou National Forest in Idaho, Jensen (1983) estimated erosion using three different (C) factors. He used the Vegetation Management (VM) factor (Warrington 1980), the National (C) factor for rangelands - Range (C) (USDA Soil Conservation Service 1977a) and a (C) factor developed for the state of Idaho (USDA Soil Conservation Service 1977b). His results showed poor correlation between the Idaho state (C) factor and actual soil erosion. He also found erosion rates were consistently overestimated when the (VM) and Range (C) factors were used, but both techniques showed a high correlation ($r^2 = 0.99$ and $r^2 = 0.97$ respectively) with actual soil loss rates. Gebhardt (1982) and Page (1982) also found the USLE to be quite valuable as a relative estimator. Gebhardt feels that persons intending to predict soil losses should place great effort on (C) factor selection and support their conclusions with field data.

Work by Dissmeyer and Foster (1981) has resulted in the use of nine subfactors for improvement of (C) value estimators on forest lands. These sub-factors are:

1. Amount of bare soil
2. Canopy
3. Soil reconsolidation
4. High organic content
5. Fine roots
6. Residual binding effects
7. On-site storage
8. Steps
9. Contour tillage

Their recommendation is that Table 11 in the USDA Handbook 537 entitled, Predicting Rainfall Erosion Losses: A Guide to Conservation Planning (USDA Science and Education Administration, 1978), be replaced with their procedure. The cover coefficient is a critical component to correctly estimate soil loss. Techniques must be developed to accurately derive this factor for rangelands.

USLE on pinyon-juniper woodlands. Those who have attempted to apply the USLE to pinyon-juniper woodlands have developed serious doubt concerning the appropriateness of the model for the job. Hawkins (1987) discussed the limitations imposed by the pinyon-juniper environment upon hydrologic modelling. The lack of ample moisture to create runoff is one reason for inaccuracies in hydrologic models such as the USLE. Renard (1987) discusses five significant problems associated with the use of the USLE in pinyon-juniper communities:

1) Although Hortonian overland flow probably occurs during intense storms, runoff usually occurs as a partial area phenomenon.

2) The rainfall-runoff erosivity factor considers precipitation in the form of rain; yet much of the runoff and erosion in pinyon-juniper areas is associated with snowmelt, frozen soil, and rain on snow.

3) The cover-management factor was developed for a more uniform cover than that encountered in pinyon-juniper areas.

4) The soil erodibility term in the worst condition is, historically, that associated with a fallow-tilled soil. Tillage activities are not normally encountered in pinyon-juniper communities.

5) Recent research indicates the LS factor, presented in Agriculture Handbook 537, may be incorrect for steep slopes such as are often encountered on pinyon-juniper sites.

During this study, several questions arose concerning the proper procedures for obtaining some USLE coefficient measurements. A serious problem in applying USLE to large areas is knowing how to correctly derive the slope LS factor. For purposes of the USLE, the slope length continues until flow is intersected by a gully, or until accumulation occurs. As one studies a pinyon-juniper site, it becomes obvious that accumulation is taking place on the uphill side under each pinyon-juniper tree. Also, once a stand reaches maturity, gully erosion becomes the most prevalent form of erosion, but the USLE does not account for this form of erosion.

Further refinement of the USLE will be necessary as land managers apply it to a variety of cover types and to different geographic locations. Results from the model will improve as land managers better understand its limitations and intended application, and as refinement of the coefficients more accurately account for the inherent variability of western United States rangelands.

Modified Universal Soil Loss Equation

Unlike the USLE, the Modified Universal Soil Loss Equation (MUSLE) is not limited to small watersheds. The model is designed to estimate sediment yield for single storm events. This is accomplished by substituting a runoff factor for the USLE rainfall (R) factor (Williams and Berndt 1977). As a result the model is designed to better account for soil degradation on western soils.

The MUSLE equation is:

$$Y = 11.8(Vq_p)^{0.56}(K)(C)(P)(L)(S)$$

where:

Y = Sediment yield from the basin in mg

V = Surface runoff volume for the basin is in m^3

q_p = Peak flow rate for the basin is in m^3/s.

Factors (K), (C), (P), (L) and (S) are identical to USLE factors. The peak flow q_p and runoff volume (V) are estimated using the Simulator for Water Resources in Rural Basins (SWRRB) hydrologic model (Williams and Nicks 1980).

Using SWRRB, surface runoff is computed using daily runoff values obtained from the USDA Soil Conservation Service (1972) Curve Numbers (CN). Basically, SWRRB uses the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model daily rainfall hydrology option which has modified for application to large, complex, rural basins (Knisel 1980).

As one realizes the prior knowledge and requirements associated with this model, it becomes understandable why potential users of MUSLE might be somewhat intimidated. In the future, as necessary information is summarized and presented in nomogram, chart, table or other forms, use of this model should become more common among land managers.

Selecting an Appropriate Erosion Model

There are many soil erosion models that could have been selected for this study. Though the USLE has received much criticism, it is still the model most used for soil loss estimations. It is the model currently employed by the SCS on agricultural and native rangelands.

Due to the controversy over use of the USLE, the decision was made to use estimates derived from the equation to further evaluate the validity of its application to rangelands, more specifically, the pinyon-juniper woodland type. Estimates derived from USLE were compared with field erosion measurements and correlated with satellite spectral data.

Modelling Soil Loss in the Future

The conventional means of collecting data for some of the coefficients used in the various erosion models is expensive in terms of time and money. For this reason, automated data collection merits investigation as a relatively inexpensive technique for rapidly gathering large quantities of information. There is good reason to believe several of the coefficients used in erosion modelling may be derived from satellite data, or through automated digital techniques.

A relatively inexpensive data source that few resource managers now use is digital terrain information. Digital terrain data are elevation data extracted from digitized contour plates, or from high-altitude photography (1:78,000 scale). There are two major formats of digital terrain data, the Digital Elevation Model (DEM) and Defense Mapping Agency (DMA) format. DEM data produced by the U.S. Geological Survey are recorded within the corresponding 7.5 minute USGS topographic quadrangle at 30 m (98.4 ft) sampling intervals. DMA data are available through the National Cartographic Information Center (NCIC). It is collected at approximately 80 m (263 ft) intervals and compiled into 1^{o} x 1^{o} blocks. Two data blocks are required to cover a 1^{o} x 2^{o} map (1:250,000 scale quadrangle). Several studies discuss the use of existing digital terrain data to obtain estimates for the USLE slope gradient (S) factor and the slope length (L) factor (Horvath, Klingebiel, Moore, and Fosnight 1983; Spanner, Strahler, and Estes 1983).

Studies also document the use of satellite digital data to derive the crop management (C) factor (Horvath, Klingebiel, Moore, and Fosnight 1983; Fenton 1982; Spanner et al. 1983). These researchers were primarily concerned with establishing (C) values for various forest, range, and agricultural land types. The Center for Remote Sensing and Cartography (CRSC) at the University of Utah Research Institute in Salt Lake City, Utah has completed a number of environmental projects in which digital satellite data were used to map subtle variations in semiarid and woodland plant communities (CRSC 1982; CRSC 1979; Jaynes 1982; Jaynes, Clark, and Landgraf 198l; Merola and Jaynes 1982; Merola, Jaynes, and Harniss 1983; Price, Ridd, and Merola 1985; Ridd 1983; Ridd, Christensen, Clark, and Landgraf 1980).

In contrast to previous works, Landsat spectral data were used to distinguish variations within a single cover type (pinyon-juniper) in this study. It is believed that satellite data can be used to identify relatively subtle variations within the canopy and/or ground vegetal cover. Depending on the degree of success, the results can be used over relatively large areas to obtain estimates of coefficients used in erosion modelling.

With many new computer software packages available which allow for the integration of numerous data layers, environmental researchers now have the ability to develop highly sophisticated environmental models. The spatial integrity of environmental factors can now be preserved, and analysis can be performed on these new data bases. The generation of large area data bases is now possible as a result of satellite and topographic digital data, as well as lower rates for computer time. This study represents the initial work toward automated assessment of soil erosion in pinyon-juniper woodlands using satellite spectral data. It is hoped future research will allow for the integration of digital data both in the form of satellite spectral and digital terrain data, with existing information such as soil types, vegetation types, geomorphic units, terrain, climate and others. It is believed the development of such a data base will give resource managers greatly improved information from which to make resource management decisions.

STUDY AREA

Site Location

Several factors were considered in the selection of the study area: 1) the area was required to be somewhat homogenous with respect to aspect and slope gradient, 2) a continuum of pinyon-juniper age-classes was desired within the area, 3) varying degrees of soil erosion were desired within the area, and 4) basic preliminary information was needed, such as soil survey maps, aerial photographs, orthophotoquadrangles, and quality satellite data. With these factors in mind, a study area was selected in Sanpete Valley, Sanpete County, Utah (Figure 3). Within this area, pinyon-juniper woodlands were abundant and obvious signs of accelerated erosion appeared throughout the county. Land management agencies have targeted this locale for erosion control research and are in the process of compiling soil, vegetation, and terrain field data. Quadrangles from the USGS cover the entire county, and satellite data of high quality are available.

As a result of field excursions in company with soil and remote sensing specialists, pinyon-juniper communities located approximately one mile north of the town of Fairview, Utah were selected as the primary areas of study. The area is located within the confines of the Fairview USGS 7.5 minute quadrangle. Figure 4 shows the study area boundaries and locations of the field study sites.

FIGURE 3. Sanpete County, Utah, with the Fairview USGS 1:24,000 scale quadrangle highlighted. The study was conducted within the confines of the Fairview quadrangle.

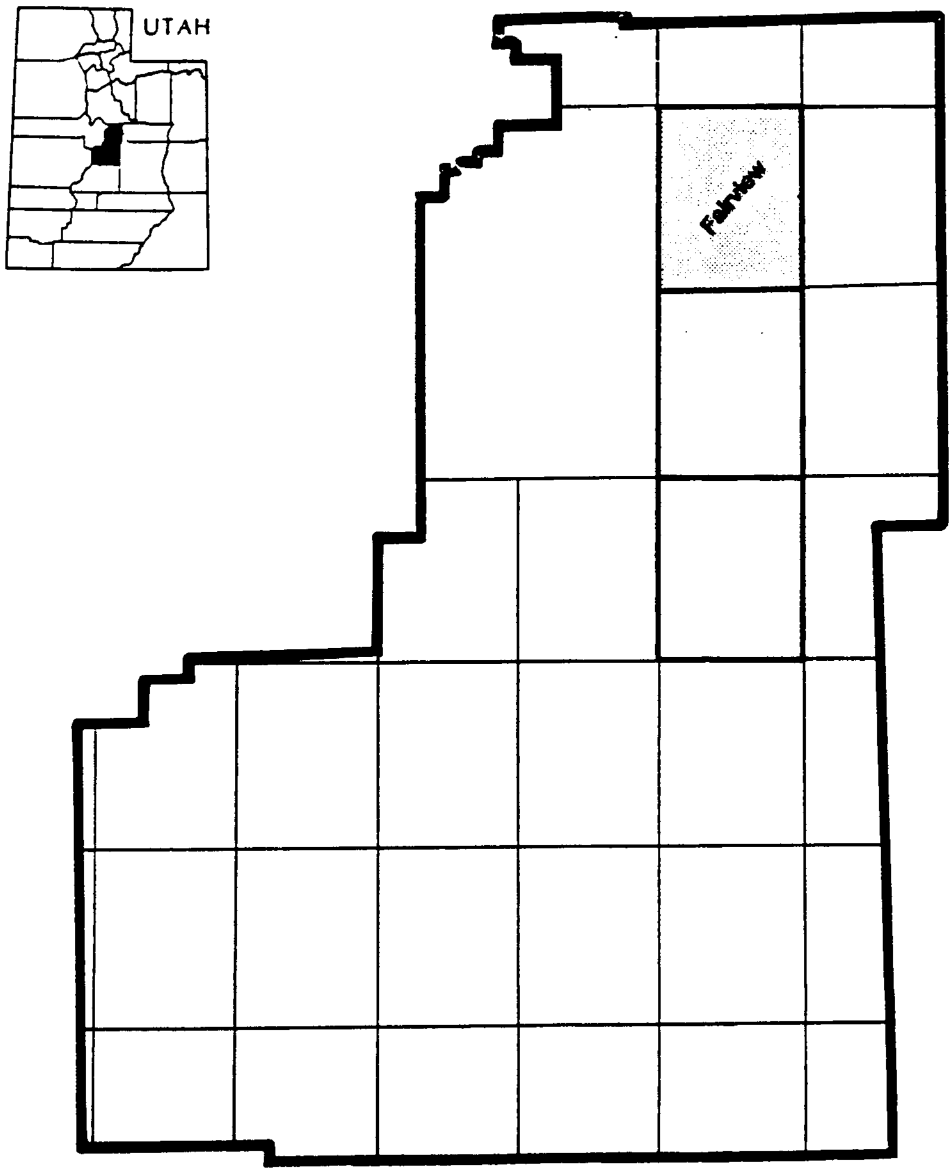
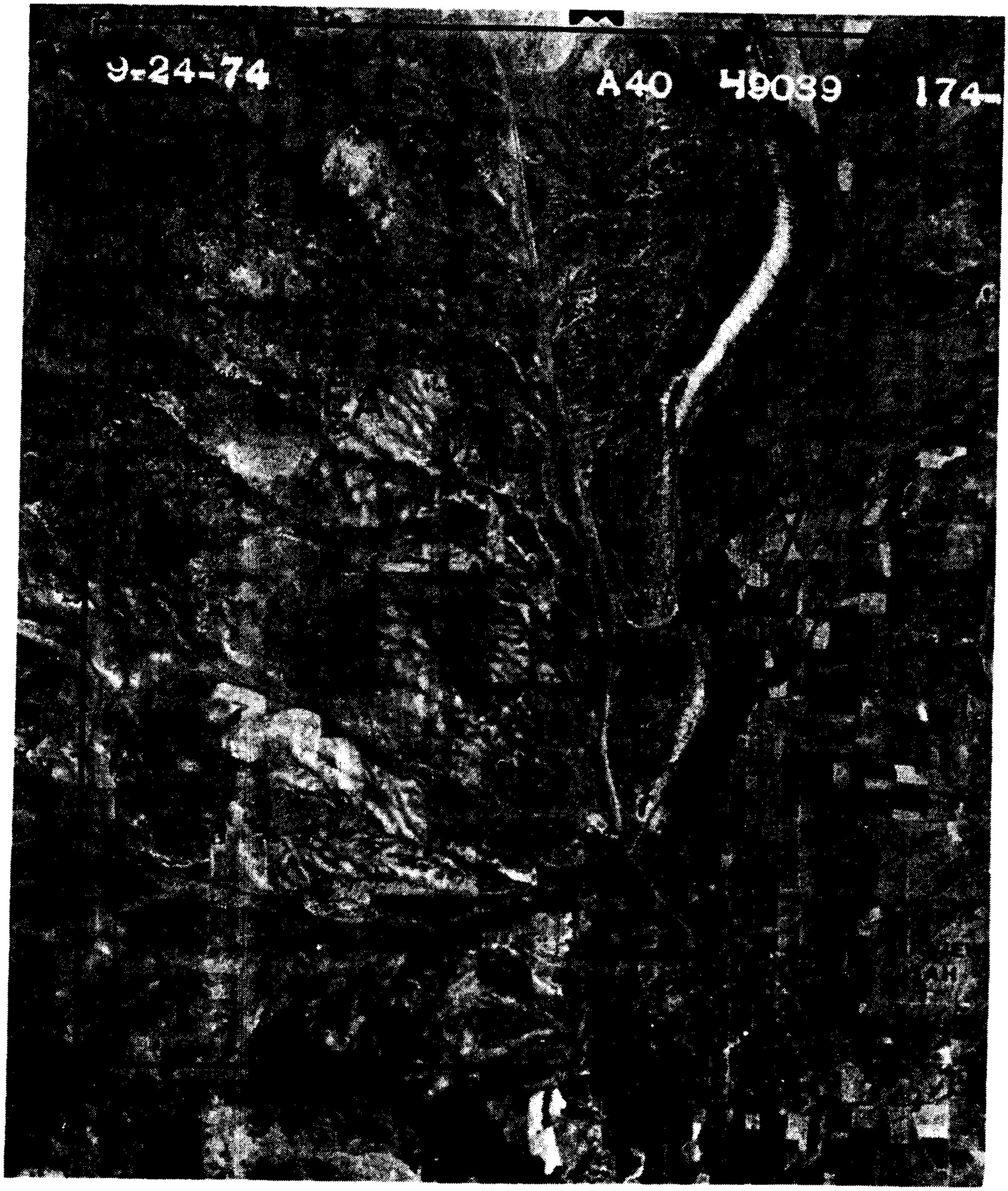

UTAH
Fairview

FIGURE 4. Aerial photograph of study area and general location of the 30 study sites.


9-24-74
A40 49039 174

Study Area Description

Valley Setting

Sanpete Valley is located approximately 105 miles south of Salt Lake City, Utah. The valley covers much of Sanpete County and a portion of south central Utah County (Figure 5). The Wasatch Plateau borders the east side of the valley, and the San Pitch Mountains border the area on the west. Physiographically speaking, Sanpete Valley lies within the transition between the Basin and Range and the Colorado Plateau provinces.

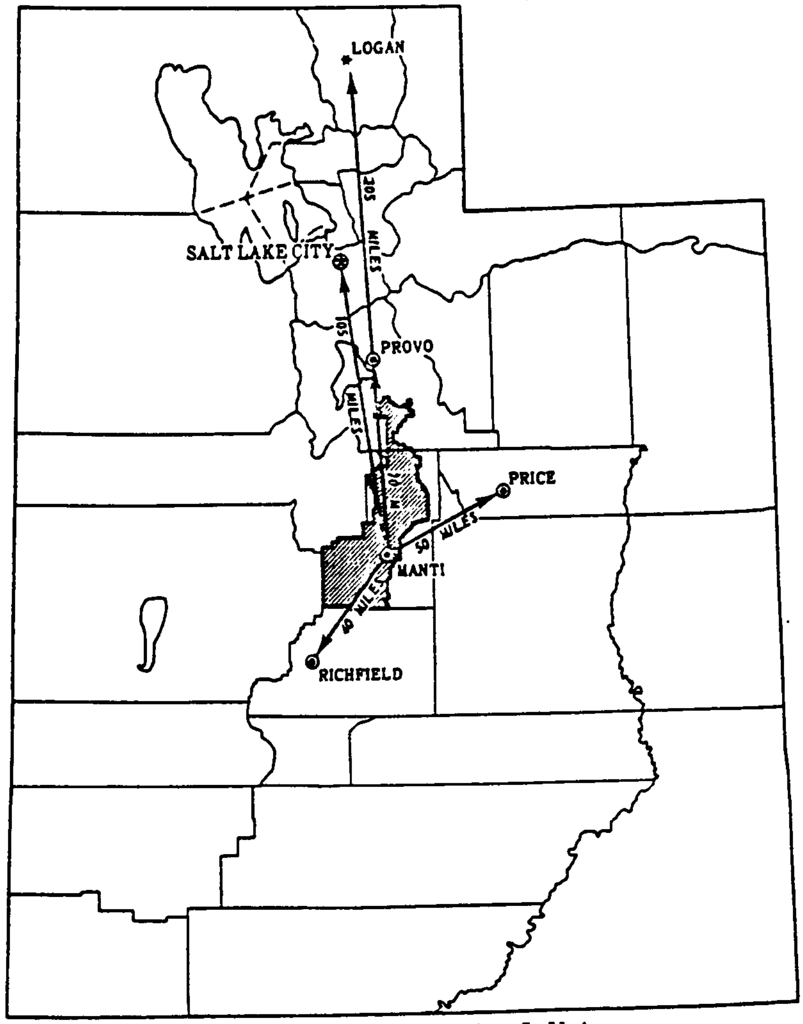
Climate

All study sites were located within an elevation zone between 1,828.8 to 2,011.7 m (6,000 - 6,600 ft). Within this zone, the average annual precipitation varies from 30.5 to 35.6 cm (12 to 14 in), and the average annual temperature ranges from 7.2^{o} to 8.3^{o} C (45^{o} to 47^{o} F). Frost free days range from 100 to 110 days (USDA Soil Conservation Service 1981).

Area precipitation during summer months is primarily from summer convectional storms and occasional frontal storms developing from the Pacific Ocean and Gulf of Mexico. Summer storms are often of the low frequency/high intensity type. Soil moisture recharge is primarily associated with winter precipitation, which usually comes in the form of snow. The winter storms most often originate in the Gulf of Alaska and move inland from the northwest. The study area also receives more moisture than surrounding areas due to the orographic effect associated with rising air masses ascending the Wasatch Plateau (elevation approximately 3,352.8 m or 11,000 ft above MSL), a few kilometers east of the study area.

FIGURE 5. Map showing the location of the Sanpete Valley and its proximity to surrounding cities. (Taken from USDA Soil Conservation Service 1981, p. vi)

*State Agricultural Experiment Station



Location of Sanpete Valley Area In Utah

Soils

From the soil survey conducted by the USDA Soil Conservation Service (USDA Soil Conservation Service 1981), it was determined that soils at the study sites are assignable to the six soil series listed in Table 1.

Seven study sites are located on soils belonging to the Atepic Series. This series is represented by well-drained soils that are less than 20.3 cm (8 in) deep over weathered shale and a surface layer of 50% or more cobble. Water runoff is rapid, and the hazard of erosion is severe.

Measurements were taken from three sites having soils of the Bagard Series. This series is commonly associated with the Atepic Series. Both series represent soils that have formed in alluvium or colluvium originating from surrounding hills. The Bagard series differs from the Atepic Series in that its soils have a higher clay content and less cobble.

The majority of the sites (17) were located on soils of the Borvant Series. This series is associated with shallow soils which range in depth from 10.2-20.3 cm (4-8 in) and lie over an indurated lime hardpan. These soils form in alluvium or colluvium derived from limestone and shale on foothills and alluvial fans.

One site was located on the Fontreen Series, which is commonly associated with both the Atepic and Borvant series. This soil type is very cobbly. Runoff is moderate and erosion is active with rills and local deep gullies.

One site was located on the Pavant Series, which is least like the other five soil types. This is a well-drained soil which is 10.2-20.3 cm (4-8 in) deep over an indurated lime hardpan. This soil forms on alluvial fans where slopes are relatively gentle (between 4-8%). The soil texture is loamy.

TABLE 1. Soil series, average bulk density, brief series, description, and study sites associated with each series.

SERIES SYMBOLS	SOIL BULK DENSITY	SOIL SERIES DESCRIPTION	SITE NUMBERS
ATF	100 lbs/cf	Atepic very cobbly silty clay loam, 8 to 40 percent slope	4, 10, 13, 17, 23, 27, 28
BCE	100 lbs/cf	Bagard very stony clay loam, 10 to 40 percent slope	2, 11, 26
BRD2	90 lbs/cf	Borvant cobbly loam, 8 to 25 percent slope, eroded	1, 21
BUD2	90 lbs/cf	Borvant-Lodar complex, 8 to 25 percent slope, eroded	3, 6, 7, 9, 12, 14, 15, 16, 18, 19, 20, 24, 25, 29, 30
FRE2	90 lbs/cf	Fontreen very cobbly loam, 20 to 40 percent slope, eroded	22
PaC	90 lbs/cf	Pavant loam, 4 to 8 percent slopes	5

Land-use History

Grazing use. The primary use of the pinyon-juniper woodlands within Sanpete Valley is early spring grazing by sheep. The land also serves as winter range for mule deer (Cluff 1987).

In the summer of 1978, the Utah Fish and Wildlife Service purchased a large block of land approximately three miles north of Fairview, Utah. Several study sites used in this study were located within this land block. The land was purchased as part of a state effort to increase and improve deer winter habitat. For the last few years, the State Fish and Wildlife Service has permitted early spring sheep grazing on this deer winter range (Christensen 1987).

Timber harvesting and fire history. While collecting field data, little evidence of timber harvesting was noted. Tree harvesting for fence posts is less common in Sanpete Valley because according to SCS standards, few trees in the area produce quality fence posts (Cluff 1987).

While collecting field data, no signs of past fire events were observed. An examination of aerial photography revealed no fire scars within the study area. It is assumed that land-use and natural changes to the environment have been relatively uniform throughout the study area.

METHODS

Satellite Digital Data Analysis

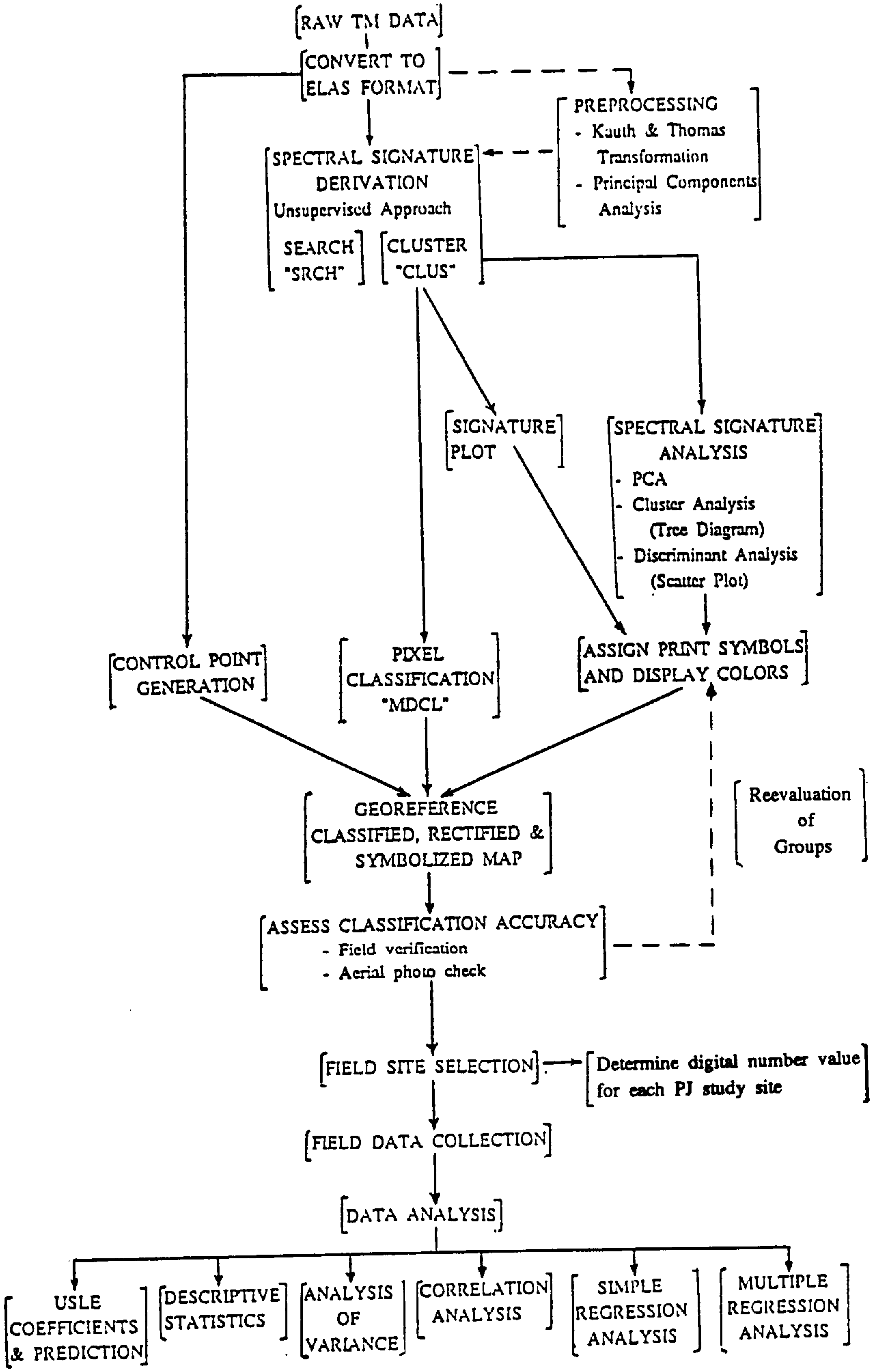
Data Selection and Preprocessing

For this study, Landsat IV Thematic Mapper (TM) was selected over the Multispectral Scanner (MSS) due to the greater spatial resolution and number of spectral bands associated with TM data. The spectral bands detected by Thematic Mapper include blue-green band 1 (0.45-0.52 µm), green band 2 (0.52-0.60 µm), red band 3 (0.63-0.69 µm), near-infrared band 4 (0.76-0.90 µm), middle-infrared bands 5 (1.55-1.75 µm) and 7 (2.08-2.35 µm), and thermal-infrared band 6 (10.40-12.50 µm). Thematic Mapper bands 1, 2, 3, 4 and 7 have a spatial ground resolution of approximately 30 x 30 m. The thermal channel (band 6) differs from the other channels, in that it has a 120 x 120 m ground resolution. The TM digital satellite data used for this study represents a June 2, 1984 scene. The data were analyzed using the ELAS software package developed by NASA's Earth Resource Laboratory (ERL) division. Analysis was done on a Prime 400 minicomputer. The TM channels used in the analysis were visible energy channels 2 and 3 and infrared energy channels 4 and 5. These bands correspond to electromagnetic wavelengths of 0.52-0.60 µm, 0.63-0.69 µm, 0.76-0.90 µm, and 1.55-1.75 µm, respectively.

Figure 6 is a flow diagram which illustrates the general steps followed in the digital image processing and data analysis procedures used in this study. Occasional reference to this diagram will help as the study procedures are explained in the following text.

After the raw data were read from the TM computer compatible tapes (CCTs), they were then converted to an ELAS format. The formatted raw data

FIGURE 6. A flow chart of the general procedures used in this study.


RAW TM DATA
CONVERT TO ELAS FORMAT
PREPROCESSING
- Kauth & Thomas Transformation
- Principal Components Analysis
SPECTRAL SIGNATURE DERIVATION
Unsupervised Approach
SEARCH "SRCH"
CLUSTER "CLUS"
SIGNATURE PLOT
SPECTRAL SIGNATURE ANALYSIS
- PCA
- Cluster Analysis (Tree Diagram)
- Discriminant Analysis (Scatter Plot)
CONTROL POINT GENERATION
PIXEL CLASSIFICATION "MDCL"
ASSIGN PRINT SYMBOLS AND DISPLAY COLORS
Reevaluation of Groups
GEOREFERENCE CLASSIFIED, RECTIFIED & SYMBOLIZED MAP
ASSESS CLASSIFICATION ACCURACY
- Field verification
- Aerial photo check
FIELD SITE SELECTION
Determine digital number value for each PJ study site
FIELD DATA COLLECTION
DATA ANALYSIS
USLE COEFFICIENTS & PREDICTION
DESCRIPTIVE STATISTICS
ANALYSIS OF VARIANCE
CORRELATION ANALYSIS
SIMPLE REGRESSION ANALYSIS
MULTIPLE REGRESSION ANALYSIS

can then be used in a variety of ways. The three major processes used in the digital analysis procedures are shown in Figure 6. The processes are: 1) Data Preprocessing, 2) Spectral Signature Derivation, and 3) Control Point Generation.

Spectral data preprocessing is used to digitally enhance features of interest. Vegetation indices are commonly used by persons wishing to emphasize the vegetal components within the data. In this study, two enhancement techniques were employed. The techniques used were: 1) the Brightness-Greenness transformation and 2) Principal Components Analysis (PCA).

1. The Kauth and Thomas (1976) transformation uses MSS 4 channel data to produce a Brightness, a Greenness, and a Yellowness Component. Crist and Cicone (1984) have developed a similar transformation model for the 7 channel TM data. They interpret their components as Brightness, Greenness, and Wetness. Crist and Cicone's TM data transformation coefficients were used in this study in an attempt to increase separability of vegetation types. Three transformed data channels were produced. Each of the new channels was displayed on an AED color monitor and a visual assessment was made of the separability of pinyon and juniper communities from surrounding vegetation types.

2. Principal Components Analysis (PCA) is used to minimize the collinearity existing between satellite channels. Components derived using PCA are often difficult to interpret, but its use as a preprocessor sometimes improves the separability of cover classes. Three Principal Components were generated and each was displayed on a monitor. Each image was examined to determine its effectiveness in discriminating pinyon-juniper from surrounding vegetation types. The color composite derived by simultaneously combining the three components was also examined.

Contrast stretching is a histogram modification technique used to enhance imagery as it is displayed on a VCR. This technique was applied to the four raw data channels, the three Crist and Cicone transformed channels, and the three Principal Component channels.

Spectral Signature Derivation and Analysis

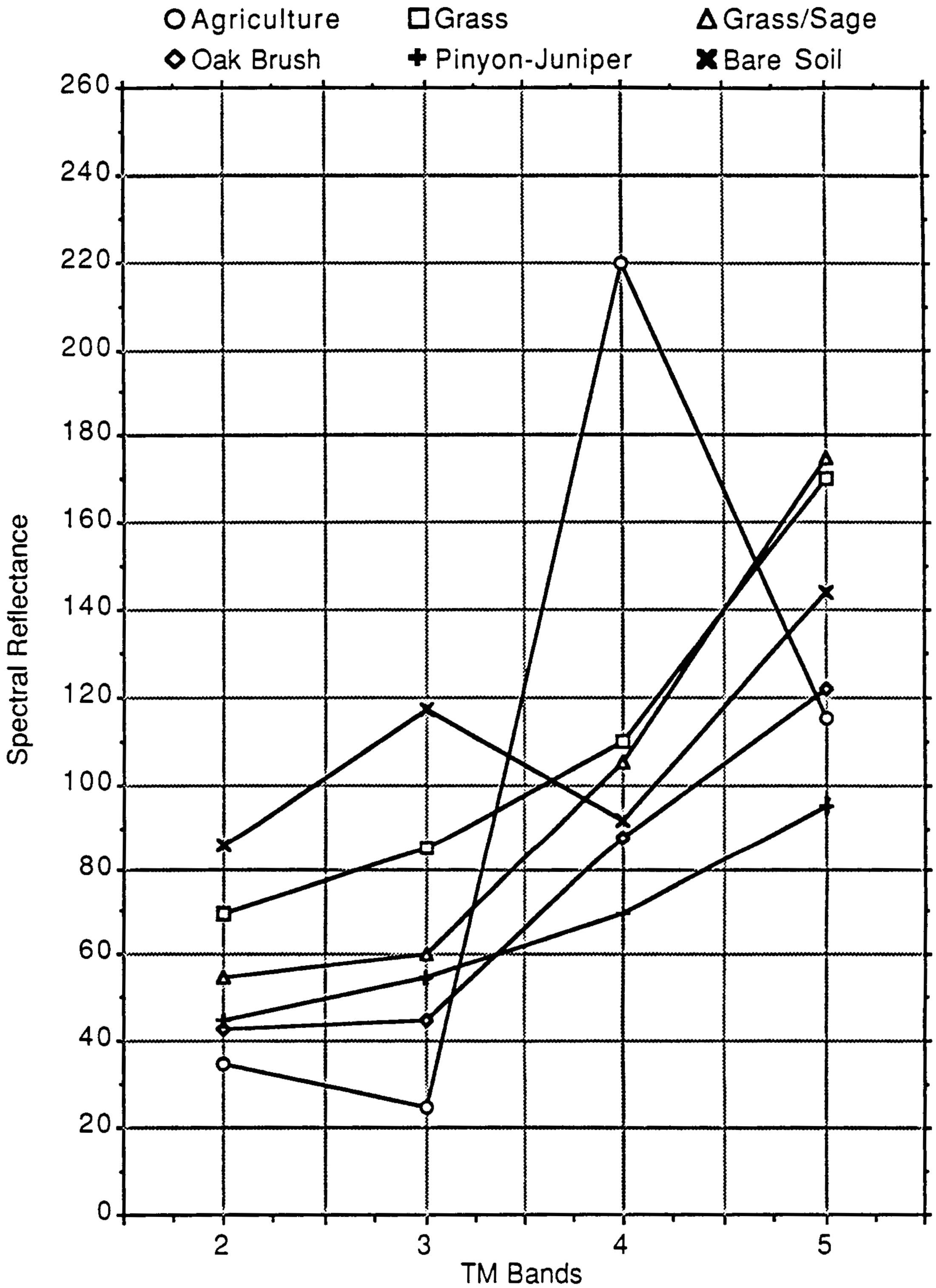
Signature derivation. Search (SRCH) and Cluster (CLUS), are ELAS modules used to generate "spectral signatures," which are also referred to as "spectral statistics." Both algorithms employ an unsupervised approach to derive their final output. SRCH uses a 3 x 3 moving window, while CLUS analyzes each picture element (pixel), individually. As a result, spectral groups generated using CLUS are more heterogeneous, and provide increased detail of land cover types. For this reason, CLUS was used to analyze the raw digital values from the four TM spectral channels.

Spectral signature analysis/land cover association. Once spectral signatures were generated, it was necessary to associate each signature with a land cover type. This was accomplished by first making general land cover/signature associations, and then gradually becoming more specific. In the laboratory, general cover types were associated with spectral signatures, using "signature plots" and a "signature scatter plot."

A signature plot was created by graphing the average signature value for each of the four TM data channels. The results produce lines across a graph which are referred to as "spectral signature curves" (Figure 7). The graphic display of the signature curves allows for the simultaneous comparison of all, or many, of the signatures associated with cover types within a study area. An understanding of the spectral curve responses, associated with various cover

FIGURE 7. Signature plot showing spectral signatures of some major vegetation-soil cover types found within the study area.

SELECTED SIGNATURES OF VARIOUS COVER TYPES



types, allows one to develop general cover-class/spectral curve associations. For example, it is known that healthy vegetation (agricultural crops) absorbs energy within the visible wavelengths (0.40 μm - 0.69 μm) (channels 2 and 3), and is highly reflective in the near infrared wavelengths (0.70 μm - 1.40 μm) (channels 4 and 5). In examining the signature plot, if such a spectral curve was observed, it was assigned to the group of signatures representing healthy vegetation.

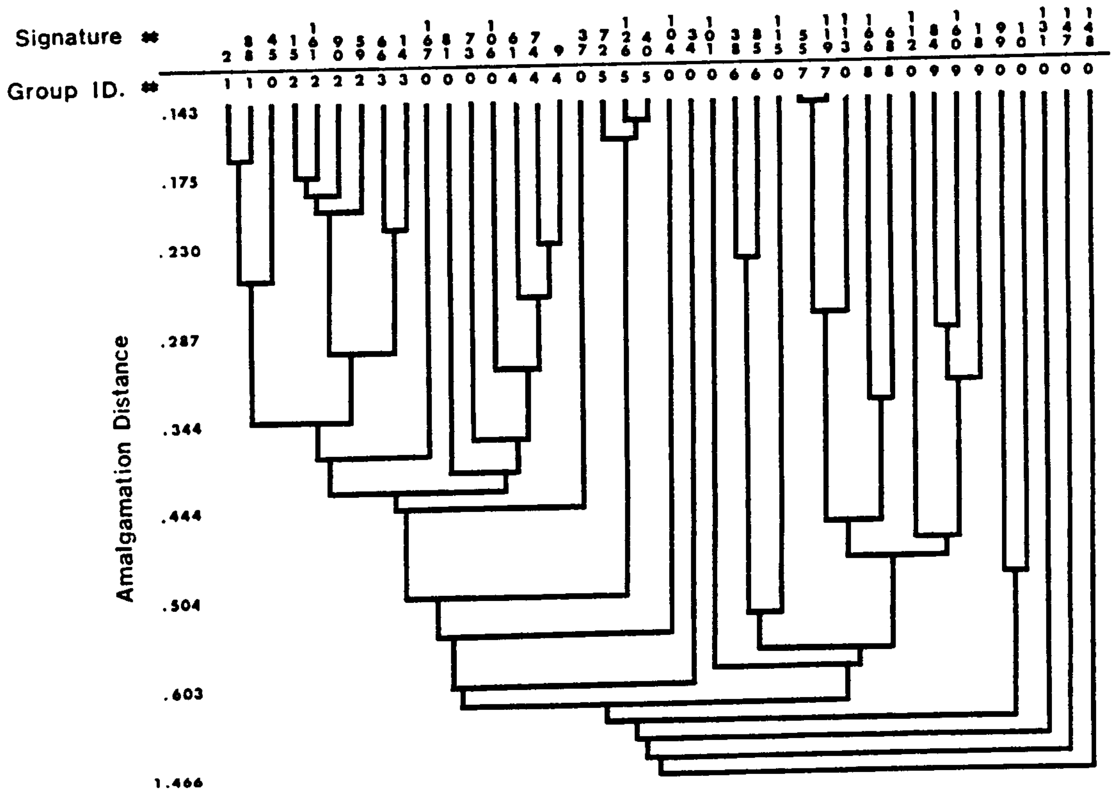
In this study, a "signature scatter plot" was also used to assist in the grouping of signatures. The generation of a signature scatter plot is accomplished through a series of steps involving the use of Principal Components Analysis (PCA), Cluster Analysis, and Discriminant Analysis.

Principal Components Analysis is used to expunge commonality existing between channels of satellite spectral data. It is also used to reduce the number of spectral channels used in digital analysis. In this study, the four spectral mean values, associated with each signature, were entered into a PCA program to derive two Principal Components. The results combined the information of visible channels 2 and 3 into one component representing the visible energy, and infrared channels 4 and 5 into a second component representing the infrared energy. Each signature is now represented by two component values, one for visible, and one for infrared energy wavelengths.

Factor scores, for the two components, were submitted to a clustering algorithm to group signatures according to spectral similarity. The signatures were then displayed in a dendrograph, also referred to as a "tree diagram" (Figure 8). Using the dendrograph, similar signatures were assigned into groups and assigned group numbers. Dissimilar signatures were left unassigned.

The Principal Component factor scores, along with the corresponding group identification number, were submitted as a data file to a Discriminant Analysis

FIGURE 8. Example of a tree diagram used to determine the spectral similarity between the 40 pinyon-juniper spectral signatures derived for this study.


Signature #
Group ID. #
Amalgamation Distance
.143
.175
.230
.287
.344
.444
.504
.603
1.466

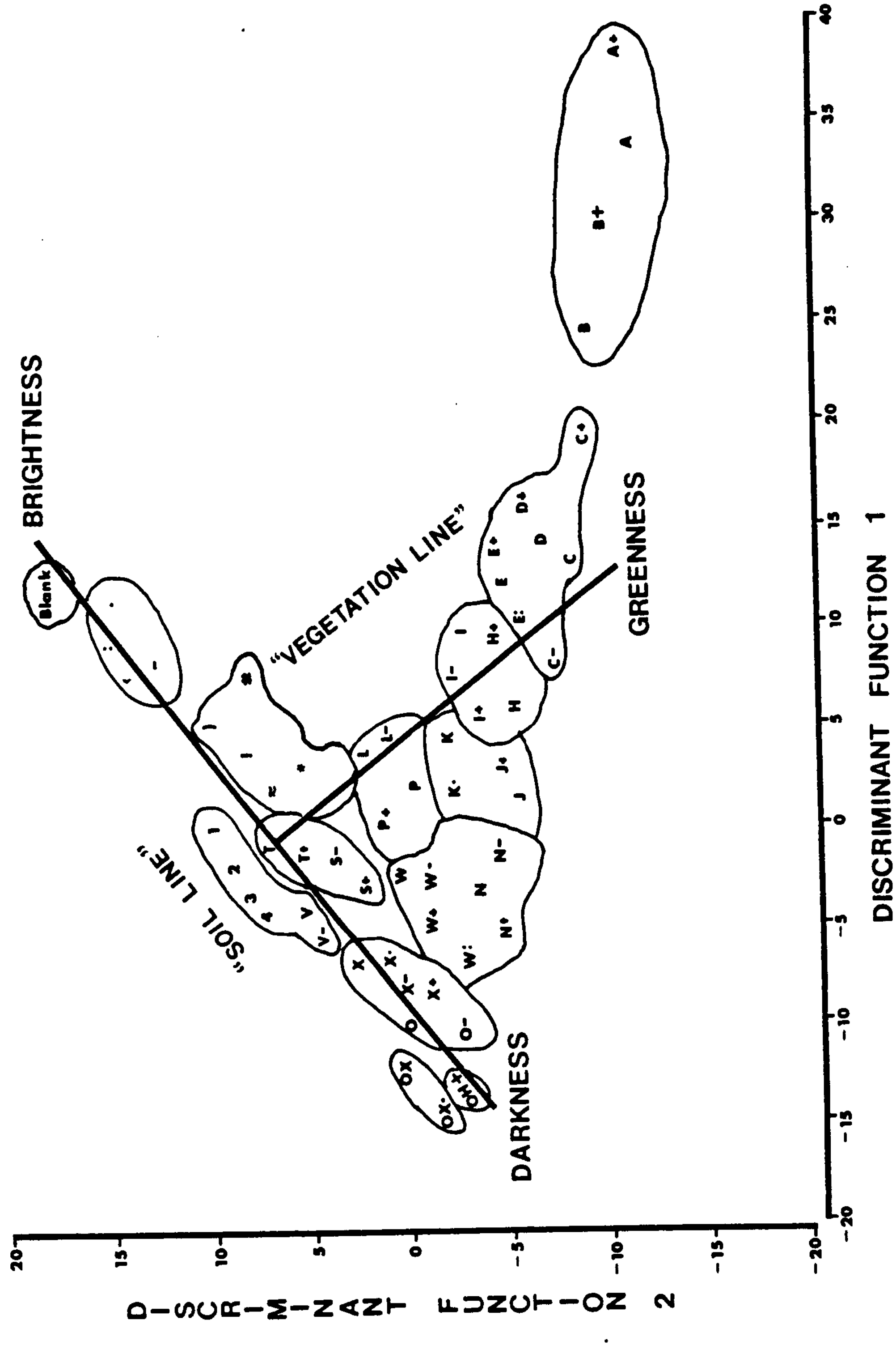
program. Using Discriminant Analysis, the statistical probability of a particular signature belonging to a particular group was determined. Unassigned signatures were assigned to the group for which they had the high probability of belonging.

Using two new functions derived from Discriminant Analysis, a two-dimensional signature scatter plot was produced (Figure 9). The two discriminant functions describe signature response as it relates to variation in the visible and infrared electromagnetic wavelengths. The spatial arrangement of signatures on the scatter plot resembles a triangle or pyramid, with the three corners representing extremes in "GREENNESS," "DARKNESS," and "BRIGHTNESS" (Figure 9). By examining the spectral signature curves, one can establish the "corner signature" representing the greenest cover type within the study area. This same technique is applied to determine the "corner signatures" representing the darkest and the brightest land cover types. By drawing a line from the "DARKNESS" corner to the "BRIGHTNESS" corner, an axis is established which is commonly referred to as the "SOIL LINE." The "SOIL LINE" is most descriptive of brightness variation in soil color. As one would assume, soils at the "DARKNESS" end of the axis are darkest, usually possessing higher amounts of moisture and organic matter, and soils at the "BRIGHTNESS" end are typically drier and devoid of vegetation and organic matter.

By drawing an axis perpendicular to the "SOIL LINE" and toward the "GREENNESS" corner, a second axis is establish which is descriptive of variations in vegetation.

Using the discriminant scatter plot, coupled with the spectral signature curves, it was possible to assign each signature to a general land cover type. Knowing the general cover type associated with each signature is useful when assigning print symbols and colors to represent each signature. For example,

FIGURE 9. Example of a discriminant analysis scatter plot used in assigning print symbols, or colors, to individual signatures.


BRIGHTNESS
"VEGETATION LINE"
"SOIL LINE"
GREENNESS
DARKNESS
DISCRIMINANT FUNCTION 1
DISCRIMINANT FUNCTION 2

signature curves characterizing healthy vegetation are usually assigned print symbols that would intuitively be interpreted as agriculture (i.e., the symbol "A") and signatures characterized by low reflectivity in all channels, are given dark print symbols (i.e., over striking of symbols O, H, and :). In this study, signature curves displaying the spectral characteristics of agriculture were assigned varying shades of red, water blues, natural grasslands yellows, deciduous trees and shrubs greens, etc. The print symbols and colors assigned to each signature were stored as data files, to be used as input during the classification procedure.

Spatial Analysis of Digital Data

Classification. Classification of the entire study area was accomplished using an ELAS program called "MDCL," which stands for Maximum Distance to Mean Classifier. This algorithm was used to assign each pixel within the study area to a spectral class. Spectral classes are defined by the statistics unique to each signature. The results is a classification output file, with all pixels assigned to one of a possible 169 spectral classes.

Control point generation/geographical referencing. Using an image display of the raw satellite date (Figure 10), 40 control points were located and their corresponding line and element (row and column) addresses were determined. The same 40 points were located on the Fairview 7 1/2 minute USGS orthophoto-quadrangle, and a Tektronix digitizing tablet was used to estimate the Universal Transverse Mercator (UTM) map coordinates for each point. By combining the UTM coordinates with the line and element pixel addresses, a ground control-point data file was created. The ELAS module, "PMGE," uses the coordinates stored in the control-point file to calculate a transformation matrix and geographically reference the raw data.

FIGURE 10. A false color composite image of the study area. The image was created by using raw TM satellite digital data.

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Map and image display of cover-classes. The georeferenced classified data were displayed in printmap form (Figure 11) and on a color monitor (Figure 12). The printmap was generated using the ELAS module "PCLS," which builds a classified map file by integrating both the georeferenced classified data and print symbol files. To produce the classified color display image, the ELAS "COMD" module is used to integrate the georeferenced data file with a color "lookup table."

Selection of Field Study Sites

Cover-class refinement. Both the color display map and printmap outputs were used to refine the cover-classes. A large-frame process camera was used to photographically reduce the printmap to USGS 7 1/2 minute (1:24,000) scale. The rescaled printmap was registered to the Fairview orthophotoquad, and cover-class symbols were associated with ground cover types identified using aerial photography. Ground cover types on the photos were established from field observations and low altitude (approx. 1:15,000 scale) 35 mm ektachrome slides. By association, it was determined that of the 169 original signatures, there were 40 signatures representing various pinyon and juniper cover types.

Pinyon-juniper signature analysis. Using the 40 signatures, a new discriminant scatter plot was made. The "SOIL LINE," and the "VEGETATION LINE" were both superimposed on the plot. Field investigation revealed that signature variation along the "VEGETATION LINE" could be equated with varying cover mixtures of pinyon-juniper and gambel oak (Quercus gambelii). It was decided to exclude these statistics, and use only signatures representing sites where pinyon and juniper were the predominant woody species.

FIGURE 11. A printmap of the study area. Most of the alpha symbols found on the printmap represent areas occupied by pinyon-juniper woodlands. The print symbol (/) represents agricultural lands, (:) represents sage/grasslands, (*) represent oakbrush and white areas are for escarpments and bare ground.

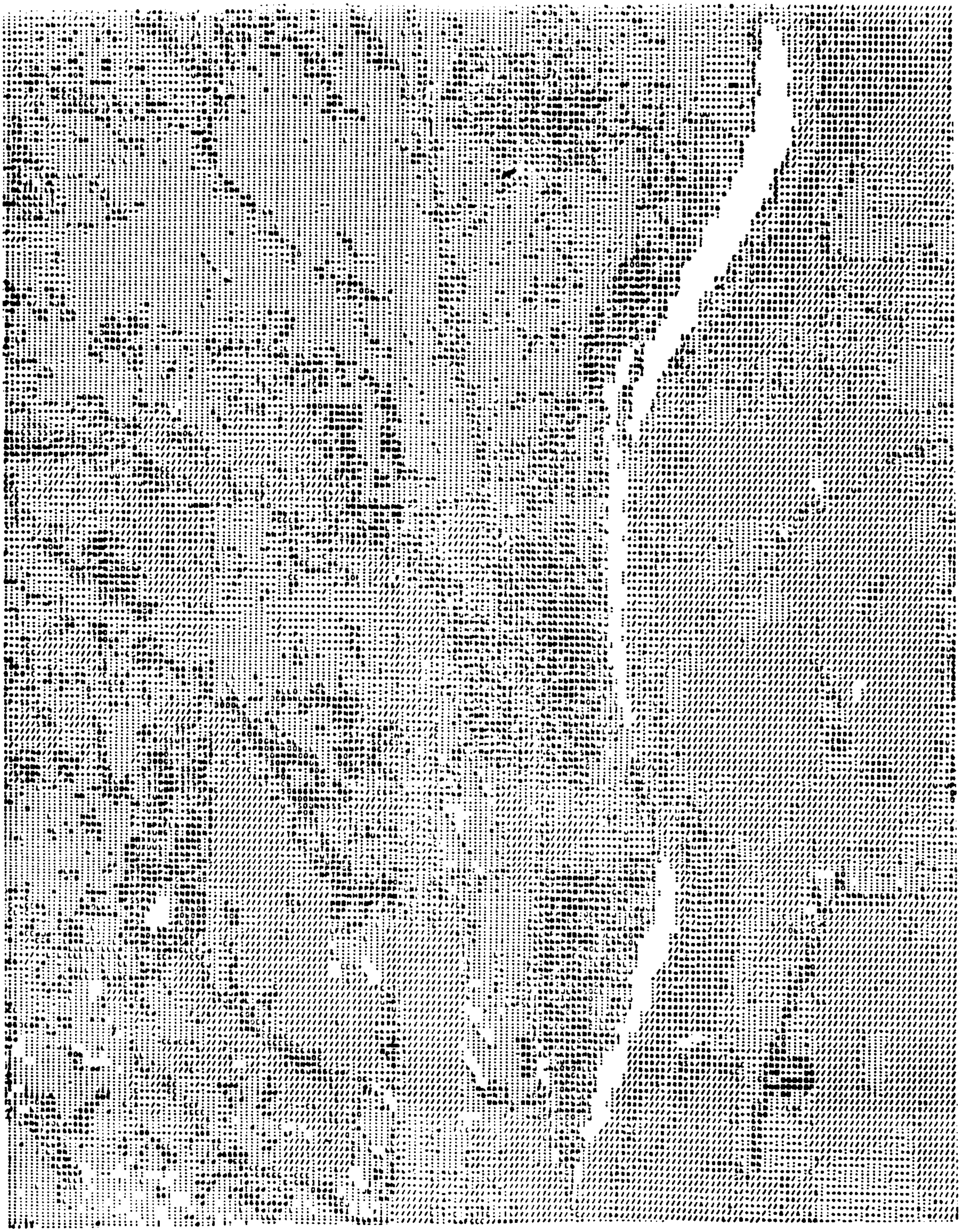

FIGURE 12. Classified color image map showing the distribution of vegetation types within the study area. This is a photograph of the final classification map generated for the study area. The three shades of purple represent the three pinyon-juniper groups used in this study, with dark purple for the dark pinyon-juniper sites, medium for medium, and so on. Some of the other prominent vegetation types of the lowlands are agriculture (bright red), oakbrush (green), sage/ grassland (yellow), and riparian habitat (dark red).

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By comparing spectral curves, and studying the Cluster Analysis dendrogram, the pinyon-juniper signatures were originally broken into four major groups. Later, Groups 3 and 4 were combined because Group 4 was inadequately represented throughout the study area.

A new print symbol list was devised, where all signatures within one of the three groups were assigned the same symbol. Signatures at the darker end of the "SOIL LINE" were assigned to Group 1 and symbolized on the printmap by overstriking characters "H," "O," and ":." The second group was assigned the character "P," and the third group was symbolized by either the letter "L" or "K." (Originally, "L" for Group 3 and "K" for Group 4) Using the new symbol list, a new printmap was generated and photo reduced to the 7 1/2 minute quadrangle scale. A color image was also created for display on the color monitor (Figure 12). Three shades of purple were assigned to the three pinyon-juniper spectral groups. Dark purple was used to represent the dark pinyon-juniper types, medium for the medium types and light purple for the brightest pinyon-juniper sites.

Field site selection. From the newly derived printmap, areas represented by homologous clusters of pinyon-juniper pixels, were located. The minimum group size used was a 2 by 2 (60 x 60 m) pixel cluster. It was determined that this was the smallest study site that could be accurately located in the field. Study sites for each of the three groups were randomly selected throughout the study area.

Study site spectral values. Using the color image display (Figure 12), study sites were located throughout the study area. Sites were established only where 2 x 2 pixel homologous groups where found. As each site was located, the spectral value for channels 2, 3, 4, and 5 were obtained using the "Read Value" option in ELAS. Values for all four pixels (2 by 2 cluster) were obtained, and the average spectral value for each channel, for each site was calculated. These raw spectral values was used in the creation of the spectral channel variables for CH2, CH3, CH4, and CH5. The CH variables were later used in the statistical analysis to determine the relationship between spectral reflectivity and field data.

Field Data Collection and Analysis

Ground Cover Estimates

Locating study sites. The selected study sites were located and marked on the printmap. The printmap was then registered to the Fairview 1:24,000 scale orthophotoquadrangle, and the sites were transferred onto the photobase. A visual search was made of the orthophoto to locate ground control points in close proximity to study sites. The orthophoto was also used to determine the ground distance and compass direction from the control point to the established field sites. Once ground control points were located in the field, a compass bearing was taken, and the distance to the study site was stepped off in the direction indicated by the compass. All site locations were double checked, and for some sites, triangulation techniques were used to insure accuracy. Study plots falling within an inclusion, where unnatural disturbance was evident such as wood cutting, roads, camp sites, etc., were moved in a random direction away from the disturbed area.

To avoid pseudoreplication of samples (Hurlbert 1984), all study sites were randomly distributed throughout the pinyon-juniper cover type. Site locations were determined by placing a grid over a map of the study area and selecting grid addresses which were determined using a random numbers table. For the analysis, an "observed" and "expected" frequency distribution was generated, and a chi-square goodness of fit was used to test the null hypothesis for randomness.

Four sampling variations were used to generate four different frequency distributions. The first distribution was derived by sectioning the study area into four subunits. The four sections were defined according to natural breaks in the spatial distribution of the pinyon-juniper cover type. The second frequency distribution was generated by reducing the four subunits, used in the first sample, to three subunits. (This was done to increase the size of the "expected frequency" values and to determine the test outcome when number of subunits are altered.) These first two sampling procedures were designed to test for clustering of the spectral groups within the study area. The third and fourth distributions were derived by creating three subdivisions, with 10 sites in each division. Delineation of the divisions for the third test was designed to detect stratification of spectral groups in the North/South direction, and the fourth sampling procedure was designed to test for East/West stratification of the study sites.

To avoid the bias created when small frequency values are using in a chi-square test, the values were combined until 80% of the "expected frequency" had values which were greater than five (Ebdon 1985). The critical value was determined using four degrees of freedom and a significance level of $p \leq 0.05$. Based on the test criteria, the null hypothesis was accepted in all four cases, and the spatial distribution of sites was assumed to be random.

Understory cover estimates. When confident that the site was correctly located on the ground, a 0.04 hectare (20 m x 20 m) study plot was randomly located within each site. A nylon cord was used to delineate the plot boundaries. Within each plot, the Daubenmire (1959) cover class technique was used to obtain understory ground cover estimates of percent litter, percent surface gravel, percent surface rock, percent bare ground, percent cryptogams, and percent cover of all plant species less than 1.0 m tall. Estimates were extracted from twenty 1.0 m^2 quadrats spaced in a uniform pattern throughout the plot. The cover class intervals used for estimating were:

0 = 0%	1 = 1% - 2%
2 = 3% - 5%	3 = 6% - 15%
4 = 16% - 25%	5 = 26% - 38%
6 = 39% - 50%	7 = 51% - 75%
8 = 76% - 95%	9 = 96% - 100%

The field data collection period ranged from the middle of September to the middle of November 1985. During this period, no major precipitation was recorded in the study area. Because moisture conditions were relatively uniform throughout this period, vegetation phenology, composition, and phytomass remained relatively constant.

Canopy cover estimates. Canopy cover for pinyon-juniper and shrub species, greater than 1.0 m tall, were estimated using the line intercept technique (Warren and Olsen 1964). Measurements were taken along four, 15.2 m (50 ft), transects spaced at regular intervals across the study plot. Direction of the transects were determined using a random numbers table and compass.

Vegetation indices. A plant species list was generated for the study area from the tree and understory species recorded as present within the study plots. Two lists were created: one displaying all species in alphabetical order and the other ranks all species in descending order of ubiquity as determined by a presence X frequency (P X F) index (Anderson 1964, Curtis 1959). The P X F index utilizes percent presences in the several stands and average frequency in *stands of occurrence* in the 1.0 m^2 quadrats (Warner and Harper 1972).

There was an average of 16 plant species per study site. Based on the P X F index rankings, the 16 most prevalent species were selected for analysis purposes. A prevalent species list with P X F indices for all species was constructed as described by Warner and Harper (1972).

An "erosion" index was developed by classifying understory plants as either decreaser or increaser species (Appendix A) depending upon their anticipated response to increased site degradation. Examples of plant species which were classified as decreasers are bluebunch wheatgrass (*Agropyron spicatum*), indian ricegrass (*Oryzopsis hymenoides*), and *Penstemon* spp. Examples of plants that were classified as increasers are cheatgrass (*Bromus tectorum*), houndstongue (*Cynoglossum officinale*), and prickly lettuce (*Lactuca serriola*).

All species within the study plots were identified and listed on the data forms. The number of species found within each plot was used as a measure of plant species richness (Washington 1984).

<u>Crop management (C) factor estimates</u>. Using canopy and understory cover measurements, and Table 10 in the <u>USDA Agricultural Handbook Number 537</u>, the USLE crop management (C) factor was estimated for each site and the average (C) value for the three spectral groups was determined.

<u>Soil Sampling and Analysis</u>

Within the boundaries of each study plot, three soil subsamples were collected. One subsample was taken from the middle, and the other two from corners adjacent to one another. Samples were taken only from the interspace between tree canopies. The top 20 cm of the soil profile were retained for texture analysis. The three subsamples were thoroughly mixed, and a representative sample was extracted for analysis.

The samples were analyzed to obtain soil texture. Grade class limits for the particle sizes were defined according to the classification by Allen (1974). The entire sample from each plot was weighed and sieved. Particles larger than 32.0 mm were discarded, those between 2.0 mm and 32.0 mm were separated from smaller particles, and defined as gravel. Clods, within the gravel particle size class were disaggregated by placing them on a sheet of cardboard and crushing them with a wooden rolling pin. The gravel samples were resieved, washed, dried, and weighed to determine the percent by weight of gravel for the entire sample.

From particles 2.0 mm or smaller in diameter, a 100 g sample was used to estimate percent sand, percent silt and percent clay. Estimates were made using the hydrometer technique described by Bouyoucos (1951). The Munsell (1969) Color Chart was used to describe soil color in terms of value, chroma, and hue. The USLE soil erodibility (K) factor was determined from the SCS soil survey manual (USDA Soil Conservation Service 1981).

Soil Stability Indices

The quantification of soil erosion on a site proved to be the most difficult field measurements to obtain. Due to the importance of obtaining an accurate estimate of site condition relative to soil erosion, much effort went into developing a suitable technique. Extensive literature search and numerous conversations with qualified persons produced few ideas on how to obtain this measurement. Of the few suggestions made, all were found to be either impractical or inapplicable to this study. In works by Carrara and Carroll (1979) and McCord (1987), exposed pinyon-juniper tree roots were used to index rates of soil erosion. This technique was considered for use until it was discovered that exposure of roots were practically nonexistent on pinyon-juniper stands at the study area.

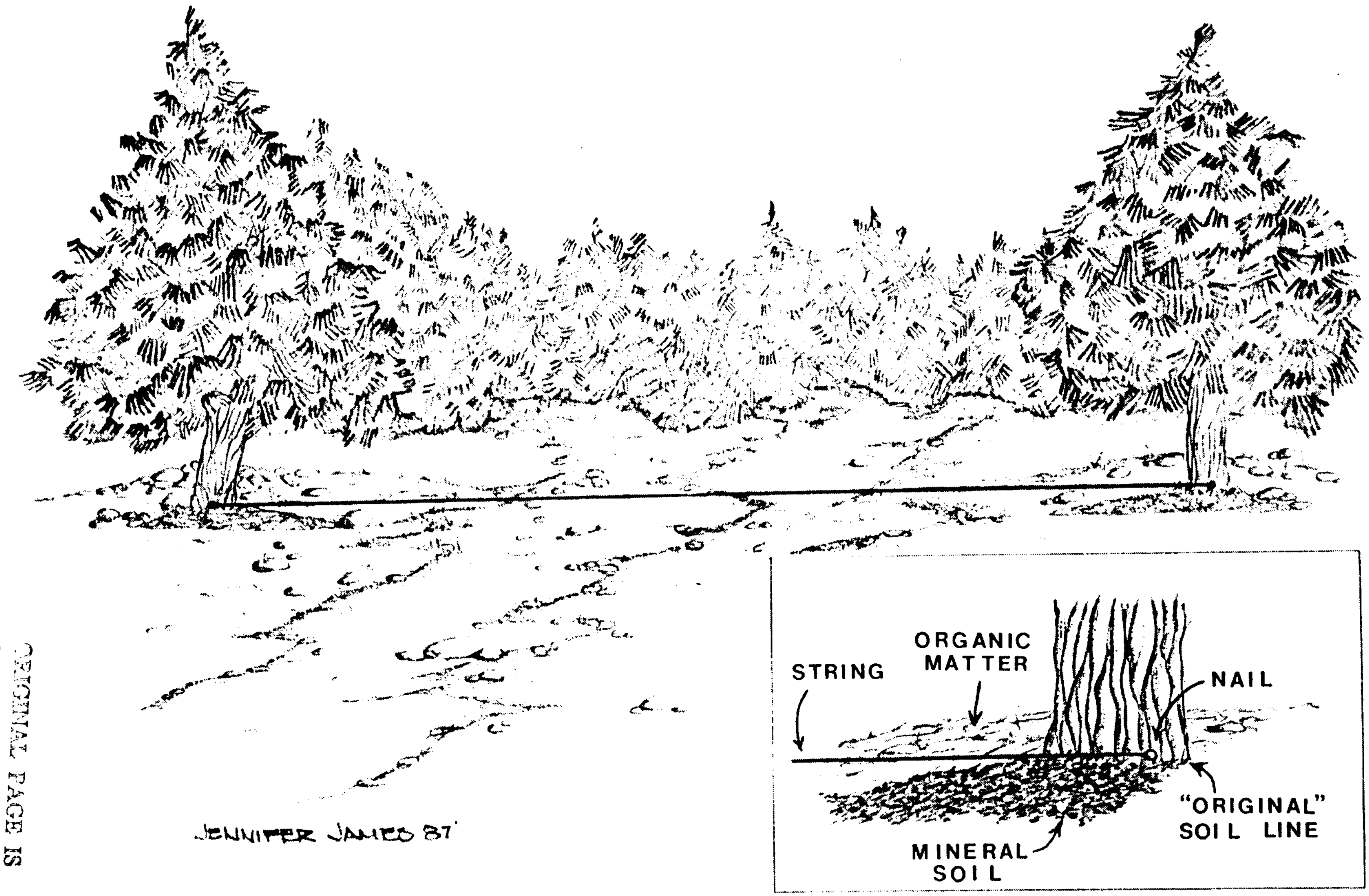
The following discussion explains the method developed in this study to generate a soil erosion index for each study site.

Soil erosion depth index. Field observations revealed that little soil erosion was evident near the trunks of the pinyon-juniper trees. Minimal erosion beneath trees was attributed to the protective effect of the cover canopy and litter. To establish a site erosion index, three tree pairs were located within, or very near, each study plot. Selected tree pairs had approximately the same trunk diameter and occurred on comparable soil and on a common slope contour (Figure 13). Pairs were selected so that the line between them was perpendicular to drainage depressions running down slope.

The soil depth, at time of tree establishment, was estimated by digging down along the tree trunk, on the down slope side. (Due to upslope debris accumulations, best results were achieved by digging on the downslope side.) An approximation of the soil depth, at time of tree establishment was marked by driving a nail into the tree trunk at the interspace between organic debris and mineral soil. A tightly stretched string was then strung between the nails marking original soil level on trunks of the tree pairs. Depth measurements from the ground to the top of the string were taken at 20 cm intervals. Measurements were confined to the interspace between tree crowns.

The approximate age of tree pairs was established using core samples, extracted 30.5 cm (1 ft) above the ground level. Tree pairs were selected that were single-stemmed, nonlobate in growth form, and had large trunk diameters relative to neighboring trees. To avoid lose or breakage of tree cores, the samples were glued on one side and inserted into 6.5 mm (1/4 in) grooves cut into

FIGURE 13. Drawing illustrating the method used to estimate soil losses from the study sites.


STRING
ORGANIC MATTER
NAIL
"ORIGINAL" SOIL LINE
MINERAL SOIL
JENNIFER JAMES 87'

a 1 in x 4 in x 1 ft pine board. The samples were polished with fine sandpaper and annual growth rings were counted twice with the aid of a microscope. One ring was assumed to equal one year of growth. Time and expense prohibited the use of cross dating to minimize age estimate error due to missing or double tree rings. It should be pointed out that trees used in this study were all located within the same general area and receive similar amounts of precipitation, similar management practices and evidence of past wildfire was not observed on any of the sites.

Using the string to ground measurements, average depth of soil lost was calculated. The average depth measurements were used to estimate total cubic meters of soil loss per study site, since tree establishment. This estimate was then converted into an erosion rate index, by dividing total cubic meters of soil loss by the average age of the tree pair. Since measurements were made between tree canopies, soil volumes loss estimates were adjusted by multiplying that value by 1.0 minus the proportion of total area covered by tree canopy. The final product was an erosion index adjusted to estimate total soil loss and rate of soil erosion from woodland interspaces. (Refer to Appendix B for a description of methods used to convert string measurements of soil loss to volumetric and weight estimates of soil loss.)

Soil penetrability index. Soil residual on a site was evaluated using penetrability measurements. This measurement was made using a sharpened, 6.4 mm (0.25 in) diameter rod fitted with a handle at one end. Penetrability was estimated by pushing the rod into the ground as far as possible and recording that depth. A total of 20 measurements was made for each site. Ten samples were taken at 2.0 m intervals along two sides of the study plot boundary.

Other Site Variables

At each site, measurements of the following factors were also made: slope gradient, slope aspect, and tree height. The average slope gradient was estimated using a clinometer. Slope aspect was determined with a compass. Average tree height was estimated with a long rod of known length. A legal description of site location was recorded, and three photographs of each plot were taken from different vantage points.

Data Analysis

Data for 30 sites (10 from each spectral group) were entered into a micro PC/XT computer for analysis. The data file was created and manipulated using MICROSTAT version 4.1, a general purpose statistical package by Ecosoft of Indianapolis, Indiana. Descriptive statistical analysis was performed using the MICROSTAT microcomputer statistics package. The statistical package SPSS was used for the multivariate statistical analysis.

After separating the 30 sites into their three spectral groups, the mean and standard deviation of each variable were calculated. One-Way Analysis of Variance (ANOVA) was used to test for significant differences between the three spectral groups. Correlation, simple regression and multiple regression analysis were used to determine the variables most affecting the TM spectral response, and the variables most descriptive of soil erosion.

Principal Components Analysis (PCA) was applied to create new spectral variables and eliminate data multiple collinearity. The technique was applied to the spectral data to create visible and infrared energy components.

RESULTS

Spectral Data Processing

Data Enhancement

Satellite data enhancement was performed using the Brightness-Greenness Transformation and Principal Components Analysis. Transformation coefficients developed by Crist and Cicone (1984) were used to produce Brightness, Greenness, and Wetness Components. The transformed data were displayed on a color monitor and visually evaluated. When the resulting images were compared to land cover types interpreted from large scale natural color aerial photography, it appeared there was insufficient definition of the pinyon-juniper cover types. The Brightness Component was most sensitive to variation in topography, primarily slope aspect. The Greenness Component was most sensitive to variation in moisture and general vegetation patterns. The Wetness Component contained little interpretable information. The lack of detail provided by the transformation is attributed to the use of general transformation coefficients. If the coefficients were developed using brightness values from the study area, as described by Jackson (1983), it is believed vegetation definition would be greatly improved.

Principal Components Analysis was used to develop new variables. It was hoped that several of the components would be sensitive to variability within the pinyon-juniper vegetation type. The new components were difficult to interpret. The first component was most sensitive to variations in agricultural cover types. The remaining components did not appear to contain any useful information about the pinyon-juniper woodland type.

There was concern in using Principal Components Analysis due to the difficulty in extrapolating results to other pinyon-juniper sites. Another study area would produce different components because PCA components are unique to the data analyzed. In an effort to keep methods as straight forward as possible, it was decided that the original nontransformed spectral data would be used.

Spectral Channel Intercorrelation

As expected, the TM spectral channels were highly correlated (Table 2). The correlation matrix showed the two visible channels (2 and 3) to be highly correlated ($r = 0.971$). Channel 4, the near infrared channel, is better correlated with channels 2 and 3, than with middle infrared channel 5. When PCA was used to create two components, channels 2, 3, and 4 were found to load most heavily on the first component and channel 5 loaded most heavily on the second component.

Spectral Signature Analysis

Spectral signatures for each of the three pinyon-juniper groups are illustrated in signature plots (Figures 14, 15, 16). These plots show the mean digital number (DN) in each channel, for each signature within its respective group. The graphed spectral response forms a spectral curve, or signature, unique to varying surficial cover types associated with pinyon-juniper woodlands. Visual analysis of the three sets of signatures shows a progressive increase in brightness as one moves from Group 1 to Group 3. This response indicates an increase in reflected energy in all four TM channels. The increase in brightness is strongly correlated with a decrease in percent tree cover and percent total living cover, which is predominantly tree cover. Correlation analysis shows that as percent

TABLE 2. Correlation between TM spectral data used in this study. The "r" values listed are for the individual raw channel (CH) data and Principal Components (PC) derived using PCA and the raw spectral data. (The critical value for $p \leq 0.05$ one tailed test is 0.307 and for the two tailed test it is 0.360.

SPECTRAL DATA:	CH2	CH3	CH4	CH5	PC1,2	PC2,2	PC1,1
Channel 2	1.000	0.971	0.943	0.876	0.842	0.536	0.978
Channel 3	0.971	1.000	0.933	0.898	0.796	0.592	0.981
Channel 4	0.943	0.933	1.000	0.894	0.770	0.607	0.972
Channel 5	0.876	0.898	0.894	1.000	0.494	0.876	0.946
PCA 1 of 2	0.842	0.796	0.770	0.494	1.000	0.014	0.748
PCA 2 of 2	0.536	0.592	0.607	0.876	0.014	1.000	0.674
PCA 1 of 1	0.978	0.981	0.972	0.946	0.748	0.674	1.000

FIGURE 14. Signature plot of the six spectral curves associated with Group 1 pinyon-juniper cover types.

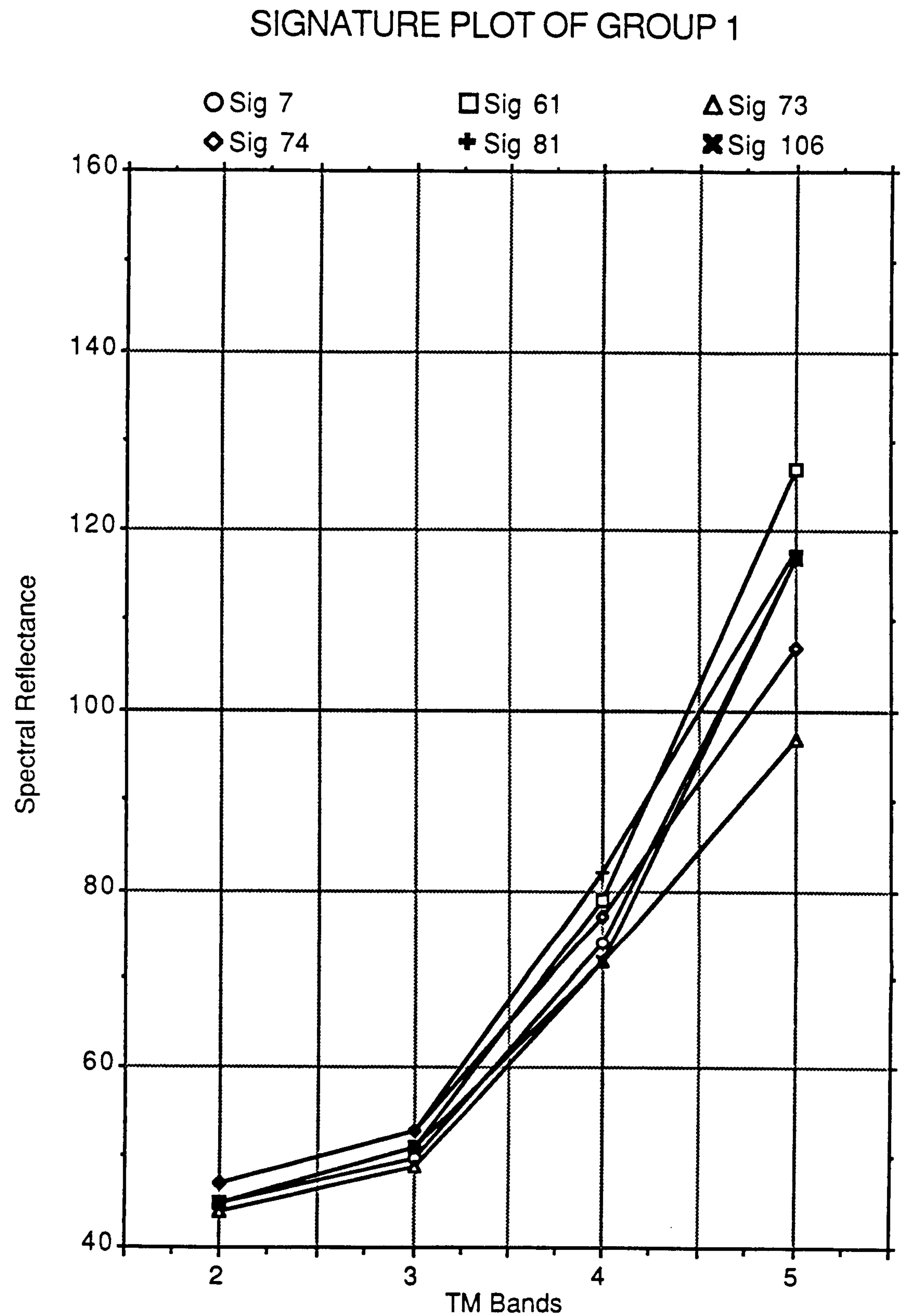

SIGNATURE PLOT OF GROUP 1
Sig 7
Sig 61
Sig 73
Sig 74
Sig 81
Sig 106
160
140
120
100
80
60
40
Spectral Reflectance
2
3
4
5
TM Bands

FIGURE 15. Signature plot of the four spectral curves associated with Group 2 pinyon-juniper cover types.

SIGNATURE PLOT OF GROUP 2

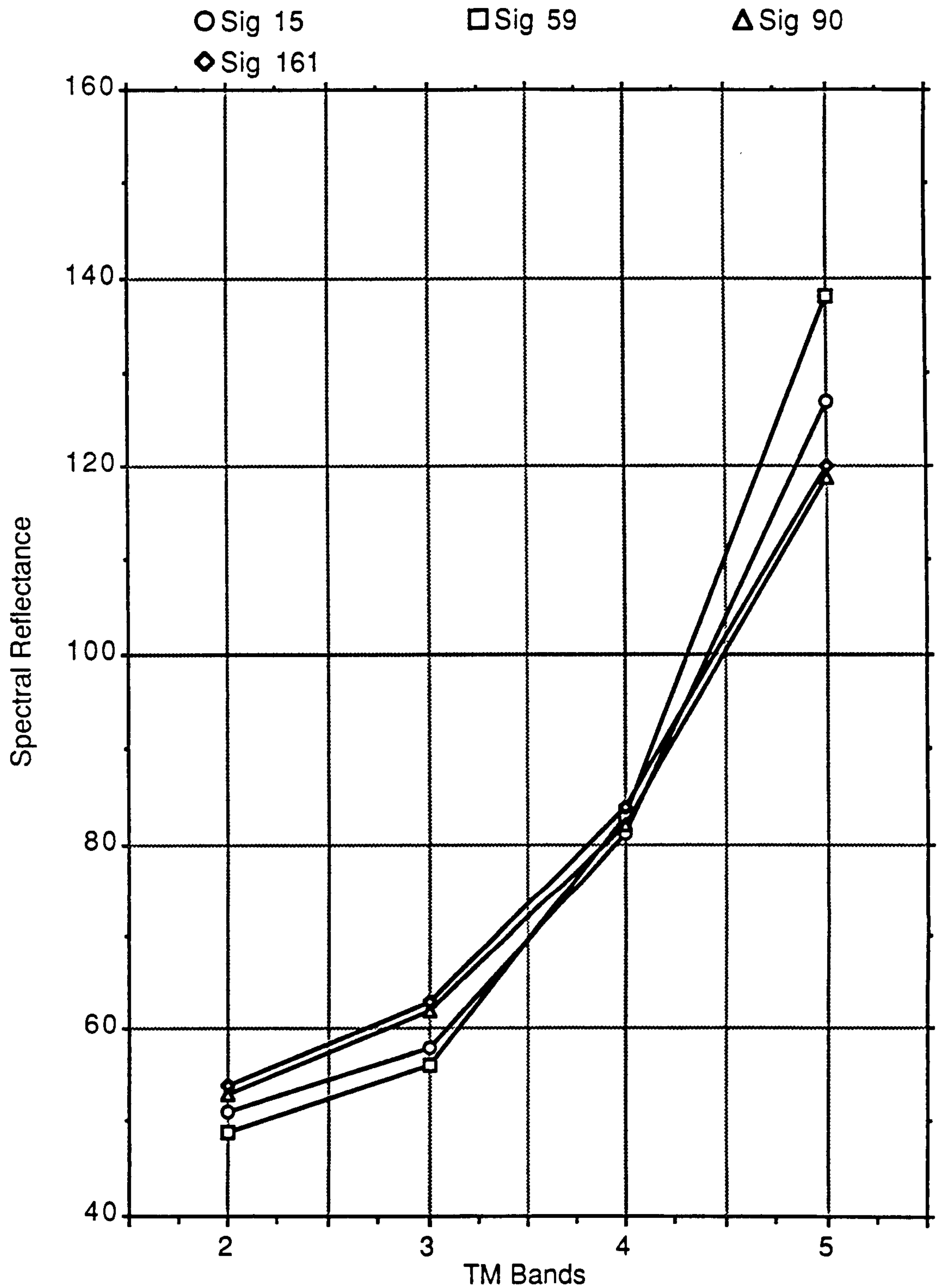
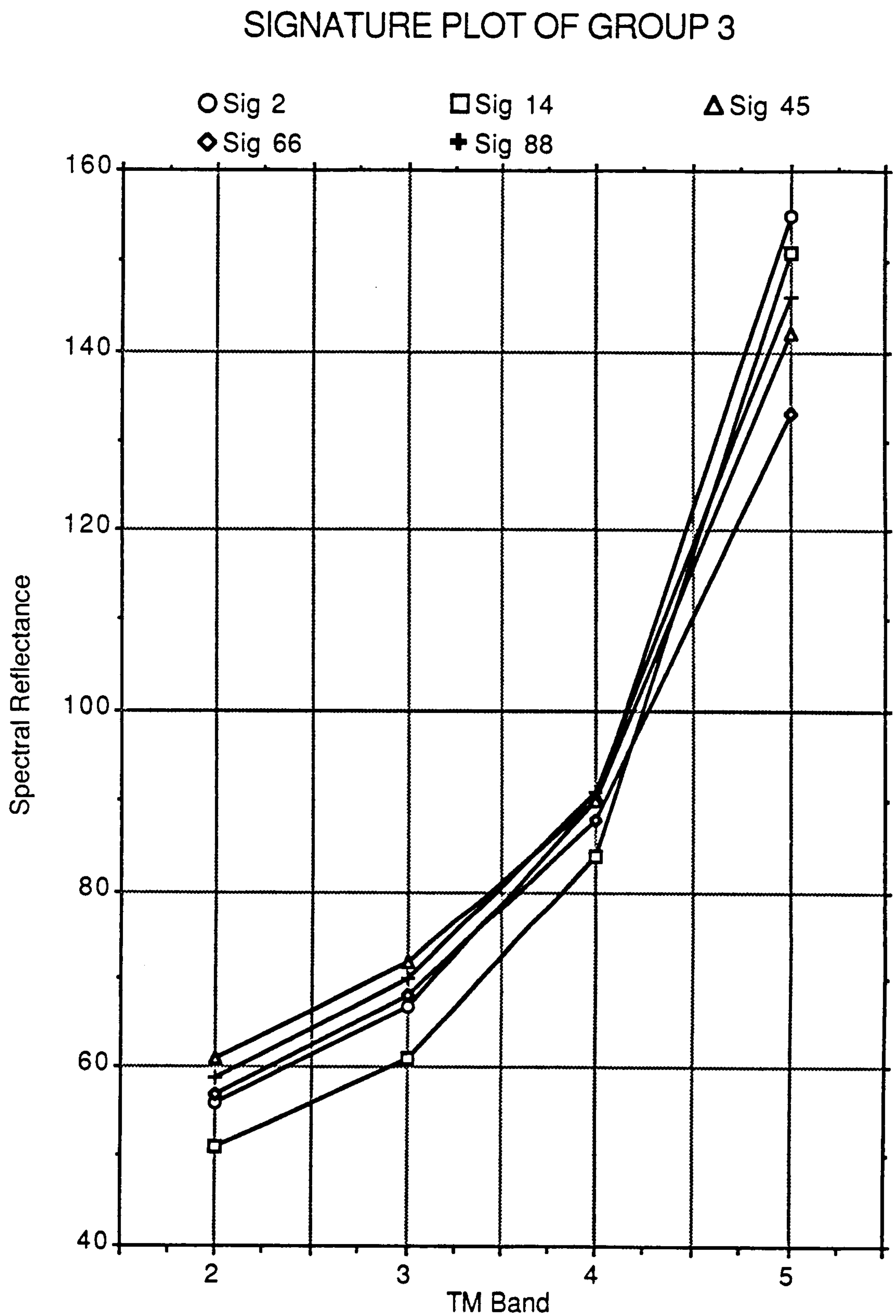


FIGURE 16. Signature plot of the five spectral curves associated with Group 3 pinyon-juniper cover types.


SIGNATURE PLOT OF GROUP 3
Sig 2
Sig 14
Sig 45
Sig 66
Sig 88
160
140
120
100
80
60
40
Spectral Reflectance
2
3
4
5
TM Band

tree cover increases, percent bare ground decreases. This is due to increased cover by tree canopy and shadowing.

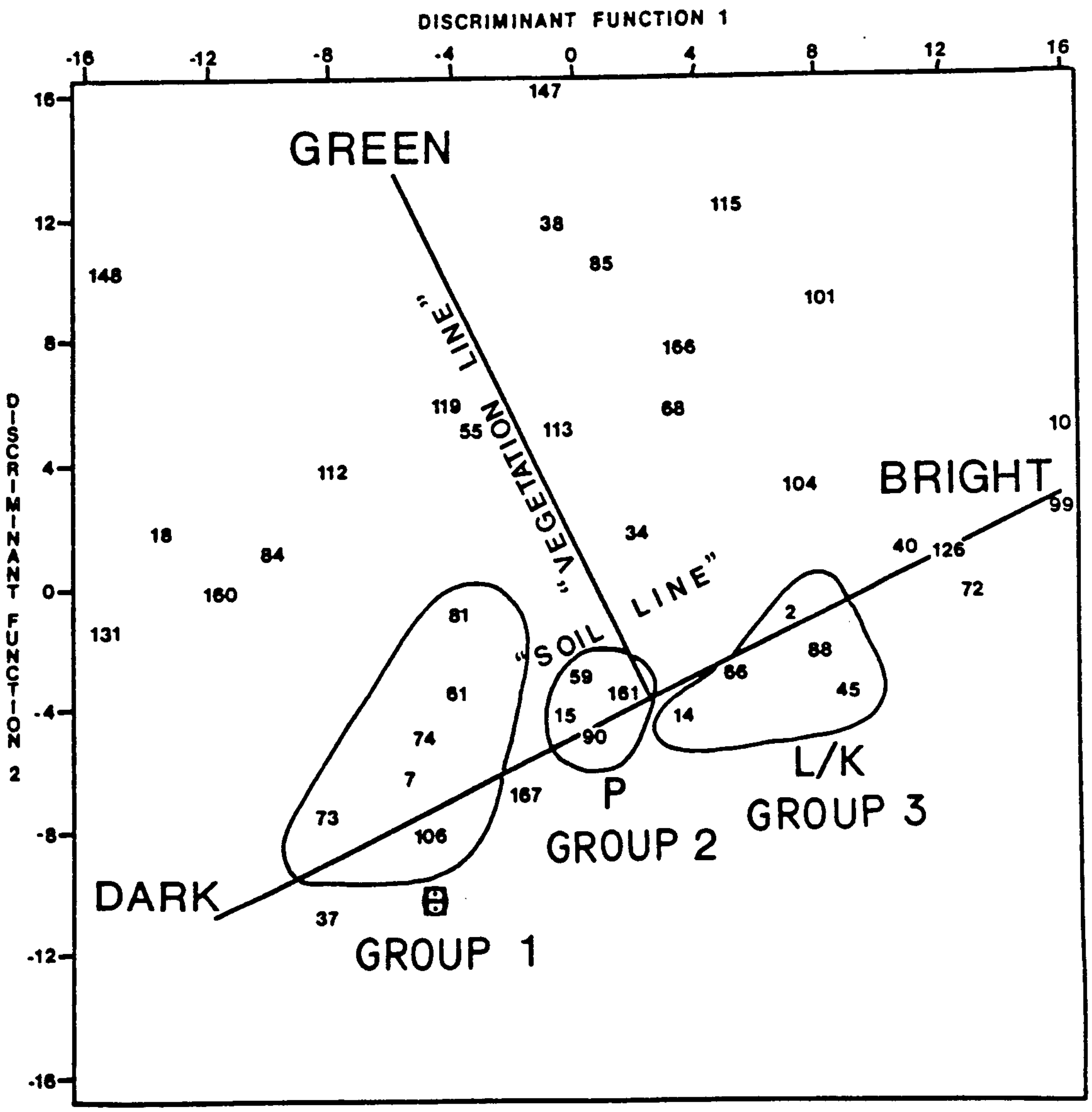
The progressive increase in soil exposure as one moves from Group 1 to Group 3 is evident in the spectral signatures associated with each group. In comparing the signatures (Figures 14, 15 and 16) between channels 2 and 3, the group curves show a progressive slope increase. Curves between channels 3 and 4 show a gradual flattening, and curves between channels 4 and 5 again show an increase in slope. The observed spectral response is indicative of a progressive decrease in vegetation and an increase in bare ground.

Discriminant Scatter Plot Analysis

Of the original 169 spectral signatures, 40 were interpreted as being descriptive of varying vegetal composition of the pinyon-juniper community type. Discriminant analysis was used to generate two descriptive functions of the data set. Using the transformed data set, a two-dimensional scatter plot of the 40 pinyon-juniper signatures was produced (Figure 17). On the scatter plot, the data distribution forms a triangular shape. Signatures in the corners of the triangle represent extremes for the darkest, lightest and greenest land cover types within the study area. The axis from the darkest to lightest signatures represents the "SOIL LINE" which is influenced by variation in soil color and moisture. The "VEGETATION LINE" axis running perpendicular to the "SOIL LINE" is descriptive of variations in vegetation types and percent vegetation cover. For purposes of this study, it was decided to relate estimates of soil erosion to homogeneous stands of pinyon-juniper. Field investigation revealed that as signatures move away from the "SOIL LINE" and towards the "GREEN" corner, the site species composition changed from predominantly pinyon-juniper, to increased dominance

FIGURE 17. Discriminant analysis scatter plot of the 40 pinyon-juniper spectral signatures. Signatures used to define the spectral characteristics of each group are circled and labeled accordingly.

C-2


DISCRIMINANT FUNCTION 1
DISCRIMINANT FUNCTION 2
GREEN
BRIGHT
DARK
"VEGETATION LINE"
"SOIL LINE"
P
GROUP 1
GROUP 2
L/K
GROUP 3

by gambel oak. As signatures moved toward the "SOIL LINE" and down toward the "DARK" corner, cover by pinyon-juniper increased and understory cover decreased. As signatures moved toward the "SOIL LINE" and the "BRIGHT" corner, pinyon-juniper cover decreased and understory cover increased. Signatures at the far end of the "BRIGHT" corner were found to represent escarpments with bright soils, very little understory, and sparsely scattered pinyon-juniper trees.

Using both the spectral signature plots and the scatter plot, 15 spectral signatures were originally assigned to four groups. Referring to Figure 17, signatures 2, 45 and 88 were assigned to Group 4. Due to the relatively few pixels assigned to these signatures, and because of their similarity to signatures 14 and 66, signatures in Group 4 were included into Group 3. Signatures 15, 59, 90 and 161 were combined to form Group 2, and signatures 7, 61, 73, 74, 81 and 106 were combined to form Group 1. On the printmap, all signatures in Group 1 were represented by the overstriking of symbols "O," "H," and ":." Signatures in Group 2 were represented by the symbol "P," and signatures 14 and 66 in Group 3 by the symbol "L," and signatures 2, 45 and 88 also in Group 3 by the symbol "K."

Field investigation revealed that signatures 40, 72, and 126 were sites dominated by sagebrush and grass, with sparsely scattered pinyon and juniper trees. Because of the few pixels assigned to these three signatures and the lack of trees, lands associated with these spectra were not included in the study. Also, signatures 37 and 167 seemed to represent a mixed pixel class. Because of the few pixels represented by these signatures, they were also excluded from any of the groups.

Ecological Description

Appendix C lists the 60 variables developed for the 30 study sites used in this study. The data listed in the appendix are the original values used for statistical analyses.

Prevalent Species

Forty-seven plant species were encountered within the 30 study sites. These plants are listed in alphabetical order in Appendix D. Cover data for each species were used to develop a presence X frequency (P X F) index. Appendix E shows all the species ranked according to their calculated P X F index values.

The average number of understory species per site was 14.4, and the average number of tree species was 1.6, combining for a study area average of 16 species per site. This calculation was used to decide the number of plant species to use in the analysis. As determined by the P X F index, the 16 highest ranking species were selected to represent the vegetation component as the most "Prevalent Species" throughout the study area. The species are ranked in descending order of ubiquity as shown in Appendix F.

The prevalent species table (Appendix F) shows the 16 most prevalent species to consist of two trees, four perennial grasses, one annual grass, four shrubs, and four perennial forbs. The mosses and lichens, primarily mosses under the trees, were collectively classified as cryptogams. Included in the table are the common names and alphanumeric symbols designating the lifeform type and place of origin of each species.

Table 3 shows the ranking of lifeforms and their relative importance to the study area as judged by the P X F index. Values in Table 3 show trees and perennial grass to be the most common lifeforms in the area. The remaining

TABLE 3. Ranking of plant lifeforms according to their cumulative and percent presence X frequency (P X F) index values.

LIFEFORMS:	CUMULATIVE C X F INDEX	PERCENT C X F INDEX
Trees	9854	34.2
Grasses (perennial)	7158	24.9
Grasses (annual)	3142	10.9
Shrubs	3074	10.7
Cryptogams	2890	10.0
Forbs (perennial)	2661	9.3
Forbs (annual)	0	0.0

lifeforms, with the exception of annual forbs, exhibit similar P X F index values. Annual forbs contributed little to the overall vegetation component of the study area.

Ecological Description of Spectral Groups

Using descriptive statistical analysis, the high, low, mean, standard deviation and coefficient of variation were calculated for each variable and listed for the three spectral groups. Summary tables were prepared for both the biotic and abiotic factors within the study area.

Biotic factors. Tables 4, 5, and 6 list, by spectral group, the 30 biotic factors used in the analysis. The tables show the spectral group minimum, maximum, means, standard deviation and coefficient of variation. Table 7 summarizes the factor means for each group. Table 8 lists the results from ANOVA which were used to determine whether statistical differences exist between group means.

Referring to Table 7, the percent total living cover for Groups 1, 2, and 3 is estimated at 63.8%, 54.8%, and 46.5%, respectively. Percent tree cover accounted for most of the total living cover, with values of 47.3%, 43.0% and 28.0%, respectively. Percent understory cover estimates were 17.6%, 12.4% and 19.0%, respectively. Cover estimates show the percent understory composition of Groups 1 and 2 to be a uniform mix of perennial and annual grasses, shrubs, and forbs. Cover estimates for Group 3, show a reduction of percent tree cover, and an increase in percent perennial grasses.

In comparing the groups vegetationally, the most significant differences are in the estimates for percent total living cover. Estimates for Group 1 through 3 are 63.8%, 54.8% and 46.5%, respectively. Table 8 shows the differences to be

TABLE 4. Group 1 biotic factors with the respective minimum, maximum, mean, standard deviation, and coefficient of variation values. The values listed for plant species represent percent cover.

GROUP 1 BIOTIC FACTORS:	MIN.	MAX.	MEAN	STD	CV
% *Juniperus osteosperma* (Utah juniper)	17.0	62.5	38.3	13.1	0.34
% *Bromus tectorum* (Cheatgrass)	0.0	8.8	3.1	3.4	1.10
% *Cryptogams* (Mosses and Lichens)	0.8	11.9	4.7	3.5	0.75
% *Leptodactylon pungens* (Granite pricklygilia)	0.0	10.7	1.9	3.5	1.84
% *Agropyron spicatum* (Bluebunch wheatgrass)	0.0	21.0	3.5	7.1	2.02
% *Sitanion hystrix* (Bottlebrush squirreltail)	0.0	2.2	0.6	0.7	1.17
% *Cryptantha flava* (Yellow cryptantha)	0.0	0.8	0.3	0.3	1.00
% *Penstemon spp.* (Penstemon)	0.0	5.1	0.9	1.8	2.00
% *Oryzopsis hymenoides* (Indian ricegrass)	0.0	1.6	0.2	0.5	2.50
% *Opuntia polyacantha* (Plains prickly pear)	0.0	6.5	1.0	2.0	2.00
% *Senecio multilobatus* (Lobeleaf groundsel)	0.0	0.6	0.2	0.2	1.00
% *Poa pratensis* (Kentucky bluegrass)	0.0	0.6	0.2	0.2	1.00
% *Antennaria spp.* (Pussytoe)	0.0	0.8	0.1	0.3	3.00
% *Pinus edulis* (Pinyon pine)	0.0	23.0	7.9	7.3	0.92
% *Gutierrizia sarothrae* (Broom snakeweed)	0.0	0.5	0.1	0.2	2.00
% *Chrysothamnus viscidiflorus* (Little rabbitbrush)	0.0	5.3	0.5	1.7	3.40
% Total living cover	54.4	83.4	63.8	9.1	0.14
% Understory cover	7.4	39.2	17.6	9.9	0.56
% Tree cover	17.0	62.5	47.3	12.7	0.27
Tree age (years)	60.0	108.0	93.6	14.4	0.15
% Perennial grasses cover	0.6	21.1	4.6	6.8	1.48
% Annual grasses cover	0.0	8.8	3.1	3.4	1.10
% Shrubs cover	0.0	11.2	3.5	4.6	1.32
% Perennial forbs cover	0.1	6.2	1.8	2.1	1.17
% Annual forbs cover	0.0	0.2	0.0	0.1	0.00
Plant species richness index (species/site)	11.0	20.0	15.1	2.4	0.16
% Cover by decreaser species	14.0	97.2	56.9	27.3	0.48
% Cover by increaser species	0.0	80.7	23.8	28.1	1.18

TABLE 5. Group 2 biotic factors with the respective minimum, maximum, mean, standard deviation, and coefficient of variation values. The values listed for plant species represent percent cover.

GROUP 2 BIOTIC FACTORS:	MIN.	MAX.	MEAN	STD	CV
% *Juniperus osteosperma* (Utah juniper)	16.0	52.0	37.1	11.4	0.31
% *Bromus tectorum* (Cheatgrass)	0.0	5.3	2.1	1.5	0.71
% *Cryptogams* (Mosses and Lichens)	1.5	11.8	5.0	3.3	0.66
% *Leptodactylon pungens* (Granite pricklygilia)	0.0	2.3	0.8	0.9	1.13
% *Agropyron spicatum* (Bluebunch wheatgrass)	0.0	3.5	0.8	1.2	1.50
% *Sitanion hystrix* (Bottlebrush squirreltail)	0.0	2.5	0.6	0.8	1.33
% *Cryptantha flava* (Yellow cryptantha)	0.0	2.3	0.5	0.9	1.80
% *Penstemon spp.* (Penstemon)	0.0	8.6	1.1	2.7	2.46
% *Oryzopsis hymenoides* (Indian ricegrass)	0.0	1.2	0.2	0.4	2.00
% *Opuntia polyacantha* (Plains prickly pear)	0.0	1.0	0.3	0.3	1.00
% *Senecio multilobatus* (Lobeleaf groundsel)	0.0	2.3	0.3	0.7	2.33
% *Poa pratensis* (Kentucky bluegrass)	0.0	1.0	0.2	0.4	2.00
% *Antennaria spp.* (Pussytoe)	0.0	0.7	0.1	0.2	2.00
% *Pinus edulis* (Pinyon pine)	0.0	15.0	5.3	5.3	1.00
% *Gutierrizia sarothrae* (Broom snakeweed)	0.0	1.9	0.3	0.6	2.00
% *Chrysothamnus viscidiflorus* (Little rabbitbrush)	0.0	0.0	0.0	0.0	0.00
% Total living cover	42.3	69.3	54.8	9.7	0.18
% Understory cover	5.8	21.3	12.4	4.8	0.39
% Tree cover	33.0	61.0	43.0	9.2	0.21
Tree age (years)	53.0	111.0	84.4	19.2	0.23
% Perennial grasses cover	0.3	5.0	1.9	1.6	0.84
% Annual grasses cover	0.0	5.3	2.1	1.5	0.71
% Shrubs cover	0.1	2.7	1.4	0.9	0.64
% Perennial forbs cover	0.0	13.3	2.1	4.0	1.91
% Annual forbs cover	0.0	0.2	0.0	0.1	1.75
Plant species richness index (species/site)	10.0	17.0	13.2	2.6	0.20
% Cover by decreaser species	42.4	82.7	62.4	11.9	0.19
% Cover by increaser species	6.2	44.7	25.0	13.2	0.53

TABLE 6. Group 3 biotic factors with the respective minimum, maximum, mean, standard deviation, and coefficient of variation values. The values listed for plant species represent percent cover.

GROUP 3 BIOTIC FACTORS:	MIN.	MAX.	MEAN	STD	CV
% *Juniperus osteosperma* (Utah juniper)	17.3	35.8	27.3	6.0	0.22
% *Bromus tectorum* (Cheatgrass)	0.2	4.8	2.9	1.4	0.48
% *Cryptogams* (Mosses and Lichens)	0.0	7.2	3.4	2.4	0.71
% *Leptodactylon pungens* (Granite pricklygilia)	0.0	4.0	1.4	1.5	1.07
% *Agropyron spicatum* (Bluebunch wheatgrass)	0.0	19.9	5.6	6.6	1.18
% *Sitanion hystrix* (Bottlebrush squirreltail)	0.0	2.9	1.0	1.2	1.20
% *Cryptantha flava* (Yellow cryptantha)	0.0	1.0	0.4	0.3	0.75
% *Penstemon spp.* (Penstemon)	0:0	1.6	0.4	0.5	1.25
% *Oryzopsis hymenoides* (Indian ricegrass)	0.0	3.7	0.5	1.1	2.20
% *Opuntia polyacantha* (Plains prickly pear)	0.0	1.1	0.3	0.4	1.33
% *Senecio multilobatus* (Lobeleaf groundsel)	0.0	0.2	0.1	0.1	1.00
% *Poa pratensis* (Kentucky bluegrass)	0.0	10.5	1.2	3.3	2.75
% *Antennaria spp.* (Pussytoe)	0.0	0.3	0.1	0.1	1.00
% *Pinus edulis* (Pinyon pine)	0.0	0.8	0.2	0.3	1.50
% *Gutierrizia sarothrae* (Broom snakeweed)	0.0	4.2	0.4	1.3	3.25
% *Chrysothamnus viscidiflorus* (Little rabbitbrush)	0.0	4.5	0.5	1.4	2.80
% Total living cover	35.8	64.8	46.5	9.2	0.20
% Understory cover	10.3	29.2	19.0	7.7	0.41
% Tree cover	17.3	35.8	28.0	6.4	0.23
Tree age (years)	36.0	113.0	84.5	19.8	0.23
% Perennial grasses cover	2.1	21.7	8.8	7.3	0.83
% Annual grasses cover	0.2	4.8	2.9	1.4	0.48
% Shrubs cover	0.3	9.3	2.8	2.7	0.96
% Perennial forbs cover	0.4	3.1	1.2	0.8	0.67
% Annual forbs cover	0.0	0.0	0.0	0.0	0.00
Plant species richness index (species/site)	12.0	20.0	15.6	3.1	0.20
% Cover by decreaser species	27.2	78.4	5.9	15.6	0.27
% Cover by increaser species	8.8	40.8	26.6	12.0	0.45

TABLE 7. Summary of the biotic factor mean value for the three spectral groups. The values listed for plant species represent percent cover.

	MEAN GROUP VALUES		
BIOTIC FACTORS:	Group 1	Group 2	Group 3
% *Juniperus osteosperma* (Utah juniper)	38.3	37.1	27.3
% *Bromus tectorum* (Cheatgrass)	3.1	2.1	2.9
% *Cryptogams* (Mosses and Lichens)	4.7	5.0	3.4
% *Leptodactylon pungens* (Granite pricklygilia)	1.9	0.8	1.4
% *Agropyron spicatum* (Bluebunch wheatgrass)	3.5	0.8	5.6
% *Sitanion hystrix* (Bottlebrush squirreltail)	0.6	0.6	1.0
% *Cryptantha flava* (Yellow cryptantha)	0.3	0.5	0.4
% *Penstemon spp.* (Penstemon)	0.9	1.1	0.4
% *Oryzopsis hymenoides* (Indian ricegrass)	0.2	0.2	0.5
% *Opuntia polyacantha* (Plains prickly pear)	1.0	0.3	0.3
% *Senecio multilobatus* (Lobeleaf groundsel)	0.2	0.3	0.1
% *Poa pratensis* (Kentucky bluegrass)	0.2	0.2	1.2
% *Antennaria spp.* (Pussytoe)	0.1	0.1	0.1
% *Pinus edulis* (Pinyon pine)	7.9	5.3	0.2
% *Gutierrizia sarothrae* (Broom snakeweed)	0.1	0.3	0.4
% *Chrysothamnus viscidiflorus* (Little rabbitbrush)	0.5	0.0	0.5
% Total living cover	63.8	54.8	46.5
% Understory cover	17.6	12.4	19.0
% Tree cover	47.3	43.0	28.0
Tree age (years)	93.6	84.4	84.5
% Perennial grasses cover	4.6	1.9	8.8
% Annual grasses cover	3.1	2.1	2.9
% Shrubs cover	3.5	1.4	2.8
% Perennial forbs cover	1.8	2.1	1.2
% Annual forbs cover	0.0	0.0	0.0
Plant species richness index (species/site)	15.1	13.2	15.6
% Cover by decreaser species	56.9	62.4	56.9
% Cover by increaser species	23.8	25.0	26.6

TABLE 8. Significant biotic factor differences between the three spectral groups. The significance levels were obtained using One-Way Analysis of Variance. The values listed for plant species represent percent cover.

BIOTIC FACTORS:	Group 1 vs 2	Group 1 vs 3	Group 2 vs 3
% *Juniperus osteosperma* (Utah juniper)		.05	.05
% *Bromus tectorum* (Cheatgrass)			
% *Cryptogams* (Mosses and Lichens)			
% *Leptodactylon pungens* (Granite pricklygilia)			
% *Agropyron spicatum* (Bluebunch wheatgrass)			.05
% *Sitanion hystrix* (Bottlebrush squirreltail)			
% *Cryptantha flava* (Yellow cryptantha)			
% *Penstemon spp.* (Penstemon)			
% *Oryzopsis hymenoides* (Indian ricegrass)			
% *Opuntia polyacanthà* (Plains pricklypear)			
% *Senecio multilobatus* (Lobeleaf groundsel)			
% *Poa pratensis* (Kentucky bluegrass)			
% *Antennaria spp.* (Pussytoe)			
% *Pinus edulis* (Pinyon pine)		.01	.01
% *Gutierrizia sarothrae* (Broom snakeweed)			
% *Chrysothamnus viscidiflorus* (Little rabbitbrush)			
% Total living cover	.05	.01	.05
% Understory cover			.05
% Tree cover		.01	.01
Tree age (years)			
% Perennial grasses cover			.01
% Annual grasses cover			
% Shrubs cover			.10
% Perennial forbs cover			
% Annual forbs cover		.10	.10
Plant species richness index (species/site)	.10		.10
% Cover by decreaser species			
% Cover by increaser species			

significant at the 0.05 level. The gradual reduction in percent total living cover is attributed to a decrease in percent tree cover, with the most significant difference in Group 3. Results show no significance difference in age of trees between the three groups. It should be remembered that a sampling bias was made in favor of large diameter, single stemmed trees.

Estimates show the percent total cover of vegetation understory to be similar between groups, but in comparing understory composition, Group 3 shows a significantly higher percent cover by perennial grasses.

The following biotic factors were significantly ($p \leq 0.05$) different for at least two out of the three spectral groups, percent juniper, percent pussytoes, percent total living cover, and percent tree cover.

<u>Abiotic factors</u>. Tables 9, 10, 11, 12 and 13 list results for the 21 abiotic factors used in the study. A comparison of the biotic versus the abiotic coefficients of variation indicates that the abiotic estimates usually exhibit less variation between sites.

Results show that study site locations had a predominant aspect of 200^{o}, and percent slope varied from 5% to 31%, with an average of 13.9% (Table 12). Figures in Table 13 indicate no significant difference between groups for either of these two factors.

A comparison of Table 8 with Table 13 shows ecological differences between groups are more common for abiotic factors, than for biotic factors. Since the three groups were defined strictly by differences in visible and infrared reflectivity, this would indicate that spectral variation between groups is most attributable to differences in abiotic factors.

Table 12 shows the average percent total nonliving cover constitutes approximately 50% of the ground cover. Percent surface rock is highest for

TABLE 9. Abiotic factors for Group 1 with the respective values for minimum, maximum, mean, standard deviation, and coefficient of variation.

GROUP 1 ABIOTIC FACTORS:	MIN.	MAX.	MEAN	STD	CV
% Total nonliving cover	31.7	55.2	42.8	8.2	0.19
% Surface rock cover	0.7	14.7	9.0	5.1	0.57
% Bare ground cover	7.7	31.3	17.5	7.4	0.42
% Surface litter cover	31.3	54.2	44.1	7.8	0.18
% Surface gravel cover	4.8	27.7	16.3	8.2	0.50
% Subsurface gravel cover (top 20 cm)	5.0	16.0	11.1	3.8	0.34
% Sand	16.0	58.0	38.8	14.2	0.37
% Silt	32.0	52.0	38.0	6.0	0.16
% Clay	8.0	52.0	23.2	17.0	0.73
Soil color (value)	4.0	5.0	4.6	0.5	0.11
% Slope	6.0	24.0	14.0	5.1	0.36
Aspect (degrees)	115.0	260.0	214.0	45.1	0.21
Soil surface penetration (cm)	16.9	29.7	21.4	3.6	0.17
Total soil loss (m^3/ha)	637.0	1503.0	1051.2	278.6	0.27
Adjusted total soil loss (m^3/ha)*	334.0	864.0	545.5	165.4	0.30
Annual soil loss (m^3/ha/yr)	5.9	23.9	12.0	5.2	0.43
Adjusted annual soil loss (m^3/ha/yr)*	3.1	9.8	6.1	2.4	0.39
TM channel 2 digital number	45.0	47.0	46.0	0.8	0.02
TM channel 3 digital number	51.0	54.0	52.5	1.3	0.03
TM channel 4 digital number	73.0	78.0	74.8	1.9	0.03
TM channel 5 digital number	108.0	123.0	116.5	5.8	0.05

*Both adjusted soil loss estimates have been modified by subtracting, from the total estimate, the percent of the area occupied by trees.

TABLE 10. Abiotic factors for Group 2 with the respective values for minimum, maximum, mean, standard deviation, and coefficient of variation.

GROUP 2 ABIOTIC FACTORS:	MIN.	MAX.	MEAN	STD	CV
% Total nonliving cover	39.7	66.6	57.5	9.1	0.16
% Surface rock cover	0.5	30.3	15.3	7.7	0.50
% Bare ground cover	11.7	28.6	17.0	5.2	0.31
% Surface litter cover	25.0	42.5	33.9	5.7	0.17
% Surface gravel cover	4.2	36.0	25.2	10.1	0.40
% Subsurface gravel cover (top 20 cm)	7.0	20.0	14.8	4.2	0.28
% Sand	24.0	60.0	38.1	10.2	0.27
% Silt	31.0	54.0	42.9	8.2	0.19
% Clay	8.0	42.0	19.0	11.1	0.58
Soil color (value)	3.0	5.0	4.1	0.6	0.15
% Slope	7.0	31.0	14.2	6.8	0.48
Aspect (degrees)	45.0	253.0	209.8	65.4	0.31
Soil surface penetration (cm)	9.9	30.8	20.8	7.5	0.36
Total soil loss (m^3/ha)	1013.0	1867.0	1305.9	247.5	0.19
Adjusted total soil loss (m^3/ha)*	608.0	846.0	728.1	86.3	0.12
Annual soil loss (m^3/ha/yr)	10.1	25.7	17.2	5.1	0.30
Adjusted annual soil loss (m^3/ha/yr)*	6.6	12.3	9.4	2.0	0.21
TM channel 2 digital number	48.0	52.0	50.3	1.2	0.02
TM channel 3 digital number	58.0	62.0	60.1	1.2	0.02
TM channel 4 digital number	78.0	82.0	79.4	1.4	0.02
TM channel 5 digital number	120.0	135.0	129.2	4.1	0.03

*Both adjusted soil loss estimates have been modified by subtracting, from the total estimate, the percent of the area occupied by trees.

TABLE 11. Abiotic factors for Group 3 with the respective values for minimum, maximum, mean, standard deviation, and coefficient of variation.

GROUP 3 ABIOTIC FACTORS:	MIN.	MAX.	MEAN	STD	CV
% Total nonliving cover	38.4	68.1	53.9	9.5	0.18
% Surface rock cover	0.1	12.2	4.8	4.4	0.92
% Bare ground cover	6.6	46.6	25.8	11.5	0.45
% Surface litter cover	20.7	53.8	31.2	10.2	0.33
% Surface gravel cover	0.4	42.0	23.2	13.2	0.57
% Subsurface gravel cover (top 20 cm)	1.0	21.0	9.6	6.8	0.71
% Sand	16.0	53.0	40.2	11.9	0.30
% Silt	23.0	50.0	33.6	7.5	0.22
% Clay	8.0	48.0	26.2	12.0	0.46
Soil color (value)	4.0	6.0	5.1	0.6	0.12
% Slope	5.0	26.0	13.5	6.0	0.44
Aspect (degrees)	25.0	270.0	172.8	80.4	0.47
Soil surface penetration (cm)	19.1	52.3	25.6	9.7	0.38
Total soil loss (m^3/ha)	1090.0	1813.0	1408.3	255.7	0.18
Adjusted total soil loss (m^3/ha)*	709.0	1360.0	1020.8	233.1	0.23
Annual soil loss (m^3/ha/yr)	13.0	31.2	17.9	5.4	0.31
Adjusted annual soil loss (m^3/ha/yr)*	8.4	20.3	12.9	3.6	0.28
TM channel 2 digital number	55.0	62.0	57.7	2.5	0.04
TM channel 3 digital number	64.0	75.0	68.6	3.6	0.05
TM channel 4 digital number	82.0	91.0	87.9	3.0	0.03
TM channel 5 digital number	135.0	151.0	144.8	5.2	0.04

*Both adjusted soil loss estimates have been modified by subtracting, from the total estimate, the percent of the area occupied by trees.

TABLE 12. Summary of the abiotic factor mean values for the three spectral groups.

ABIOTIC FACTORS:	MEAN GROUP VALUES Group 1	Group 2	Group 3
% Total nonliving cover	42.8	57.5	53.9
% Surface rock cover	9.0	15.3	4.8
% Bare ground cover	17.5	17.0	25.8
% Surface litter cover	44.1	33.9	31.2
% Surface gravel cover	16.3	25.2	23.3
% Subsurface gravel cover (top 20 cm)	11.1	14.8	9.6
% Sand	38.8	38.1	40.2
% Silt	38.0	42.9	33.6
% Clay	23.2	19.0	26.2
Soil color (value)	4.6	4.1	5.1
% Slope	14.0	14.2	13.5
Aspect (degrees)	214.0	209.8	172.8
Surface penetration (cm)	21.4	20.8	25.6
Total soil loss (m^3/ha)	1051.2	1305.9	1408.3
Adjusted total soil loss (m^3/ha)*	545.5	728.1	1020.8
Annual soil loss (m^3/ha/yr)	12.0	17.2	17.9
Adjusted annual soil loss (m^3/ha/yr)*	6.1	9.4	12.9
TM channel 2 digital number	46.0	50.3	57.7
TM channel 3 digital number	52.5	60.1	68.6
TM channel 4 digital number	74.8	79.4	87.9
TM channel 5 digital number	116.5	129.2	144.8

*Both adjusted soil loss estimates have been modified by subtracting, from the total estimate, the percent of the area occupied by trees.

TABLE 13. Significant abiotic factor differences between the three spectral groups. The significance levels were obtained using One-Way Analysis of Variance.

ABIOTIC FACTORS:	Group 1 vs 2	Group 1 vs 3	Group 2 vs 3
% Total nonliving cover	.01	.01	
% Surface rock cover	.05	.05	.01
% Bare ground cover		.05	.05
% Surface litter cover	.01	.01	
% Surface gravel cover	.05		
% Subsurface gravel cover (top 20 cm)	.05		.05
% Sand			
% Silt	.10		.01
% Clay			
Soil color (value)	.05	.05	.01
% Slope			
Aspect (degrees)			
Surface penetration (cm)			
Total soil loss (m^3/ha)		.05	.01
Adjusted total soil loss (m^3/ha)*	.01	.01	.01
Annual soil loss (m^3/ha/yr)	.05	.01	
Adjusted annual soil loss (m^3/ha/yr)*	.01	.01	.01
TM channel 2 digital number	.01	.01	.01
TM channel 3 digital number	.01	.01	.01
TM channel 4 digital number	.01	.01	.01
TM channel 5 digital number	.01	.01	.01

*Both adjusted soil loss estimates have been modified by subtracting, from the total estimate, the percent of the area occupied by trees.

Group 2 covering 15.3% of the land surface, and Group 3 is the lowest at 4.8%. For percent surface gravel, Groups 2 and 3 have similar estimates of approximately 25%, and Group 1 is lowest with an estimate of 16.3%. Percent bare ground for Groups 1 and 2 is similar at approximately 17% and Group 3 is significantly higher at 25.8%.

Litter was primarily composed of fallen juniper and pinyon debris lying under the trees. On some sites, fallen tree limbs constituted a significant portion of the litter estimate. Table 12 shows sites in Group 1 to have the highest amount of surface litter (44.1%), and Groups 2 and 3 to have similar amounts of between 30-35%.

Soil texture measurements of percent subsurface gravel, percent sand, percent silt and percent clay showed little differences between groups with the exception of Group 2, which appears to be slightly higher in percent subsurface gravel and percent silt. Interestingly, though the sites were of similar soil texture, the soil color values were significantly different between the three groups. In evaluating soil darkness, Group 3 had the lightest soils, Group 1 the next lightest and Group 2 had the darkest soils. Analysis of Variance showed all to be significant differences at the 0.05 level.

Table 12 also shows no significant differences between groups in soil penetrability, but soil erosion estimates show significant differences in soil loss. The erosion estimates indicate that the greatest amount of soil loss, since tree establishment, is from sites in Group 3, the second highest from Group 2, and the least from Group 1.

Table 12 shows the average spectral digital numbers associated with each of the groups. All four channels show a significant increase in surficial reflectivity from Group 1 to Group 3.

Table 13 lists significance levels derived from ANOVA for the abiotic factors. If one compares Table 13 with ANOVA results for biotic factors (Table 8), differences between groups appears to be more highly significant for the abiotic factors.

The following abiotic factors were found to be significantly ($p \leq 0.05$) different between at least two out of the three groups, percent total nonliving, percent surface rock, percent bare ground, percent litter, percent subsurface gravel, percent silt, and soil value. All the soil erosion estimates were found to be significantly different between groups, but two of the soil erosion estimates showed no significant difference between Groups 2 and 3. As expected, the satellite spectral variables were all significantly different for three groups.

Correlation and Simple Regression Analysis

Correlation Analysis was used to identify significant relationships between environmental and spectral measurements extracted from the 30 study sites. A correlation matrix was generated and significant relationships at $p \leq 0.05$ were displayed for examination using an X-Y scatter plot. A number of statistically significant relationships were noted and are reported in the following sections. Practical constraints did not allow for a large sample size. For this reason relationships cited are generally not strong, but each has been examined in an X-Y plot and determined to be statistically valid. Each relationship was plotted and examined to insure that single outlying points were not biasing correlation results. The following relationships, with their corresponding correlation "r" values, regression equation coefficients, and regression prediction lines, are shown in graph form in Appendix G.

Pinyon-Juniper Community Relationships

Tree cover. As expected, percent tree cover was found to be inversely associated with percent cover of understory vegetation. Correlation results indicate a decline in species richness as percent tree cover increases, but shows an increase in species richness as tree age increases. The last two relationships appear to contradict one another, but it should be remembered that larger trees were selected for use in the string measurement method; therefore tree age estimates do not necessarily represent the average age of the pinyon-juniper stand. Also, older aged stands may not be associated with an increase in percent tree cover. In this study, there was no significant relationship between tree age and percent tree cover. These results suggest that in the study area, percent tree cover and age structure are more a function of site characteristics, and less related to the age of the stand.

Negative relationships were also found between percent tree cover, and frequency of decreaser species and percent cover by perennial grasses. Percent litter, which was predominantly needles and scales dropped by the trees, was positively associated with percent tree cover. Soil value, as indexed from a Munsell Color Table (1969), showed an inverse relationship with percent tree cover. This trend showed soils darkening as percent tree cover increases.

Also, with increases in percent tree cover, the soil penetration depth of a sharpened 0.65 cm steel rod decreased. Percent exposed rock increased and percent exposed soil decreased as percent tree cover increased. All three of these relationships suggest that increases in percent tree cover are associated with shallow soils.

Understory. Understory was found to have a positive relationship with soil value. (Increases in understory were associated with brighter soils.) This is probably because pinyon-juniper cover is positively associated with darker soils, and percent cover by understory is negatively associated with percent tree cover.

Percent cover by surface rock, surface gravel, and soil gravel was found to have inverse relationships with understory vegetation. Percent exposed soil and soil penetrability were found to have positive relationships with percent understory. These relationships suggest that percent cover by understory is positively associated with deeper soils.

Percent cover by decreaser plant species was found to have a negative relationship with the USLE soil erodibility (K) factor. (As the (K) factor increases, erodibility of the soil increases.) Increaser species exhibited a positive relationship with the (K) factor. This is probably due to the fact that soils more susceptible to erosion, are usually more severely eroded.

Plant species richness index. A species richness index is sometimes used as an indication of site condition. Presumably, sites in better ecological condition generally support a greater diversity of plant species. In this study, species richness had a tendency to diminish with increases in percent cover by cryptogams. Percent cover by cryptogams was also found to increase as percent soil gravel increased. As depth of soil penetration increased, species richness also increased.

Richness of species also had a tendency to be greatest on lighter soils, and least on the darker soils. Sites of higher clay content seemed to have greater species richness, while gravelly sites were less rich in species. As percent bare ground increased, species richness also increased. This is probably due to the increased soil depth associated with sites with less tree cover and more perennial grasses and bare ground.

Soil value. Soil scientists measure soil value using a Munsell Color Chart. The brighter the soil, the higher the value recorded from the chart, or, from a remote sensing standpoint, the higher the value, the greater the amount of reflected visible and infrared electromagnetic energy. Variations in soil value (reflected light) are most often associated with parent material, or percent organic matter (Donahue, Miller, and Skickluna 1977). Since organic matter analysis was not performed on the soil samples, the variability of organic compounds between study sites is not known.

Soil value was found to be positively correlated with percent cover by perennial grasses and inversely related to percent cover by cryptogams. As percent exposed rock, percent surface gravel, or percent soil gravel increases, soil darkness also increases. Darker soils were also associated with increases in percent silt and decreases in percent clay content. Soil value was found to vary directly with the soil erodibility (K) factor, meaning the brighter soils had a tendency to be more erodible than the darker soils.

Abiotic community relationships. The percent total nonliving component (percent rock, percent gravel, and percent bare ground) of each site was found to increase, with increases in the slope gradient. As slope gradient increased, the soil erodibility (K) factor also increased. Correlation results showed percent surface gravel and percent soil gravel to be negatively associated with the (K) factor. A positive relationship was found between percent surface gravel and percent soil gravel. This relationship may seem somewhat obvious, but interestingly, only 52% of the variability in percent surface gravel was accounted for by percent subsurface gravel. (It is believed that surface erosion of the soil may account for a significant portion of the remaining variability.) Percent bare ground was found to vary inversely with percent soil gravel and percent silt, and vary directly with percent clay. Percent silt was found to have an inverse relationship with the soil erodibility (K) factor, while percent clay had a positive relationship with the (K) factor.

Environmental Associations with Spectral Data

Biotic relationship with spectral data. A negative relationship was found between percent cover by trees and all four TM channels, indicating, as percent tree cover increases, spectral brightness decreases. Percent tree cover was most highly correlated with channel 4 ($r = -0.748$) (Figure 18), and least correlated with channel 5 ($r = -0.628$). An inverse relationship was also noted between percent total living cover and all four TM channels. Percent total living cover was most highly associated with channel 4 ($r = -0.671$) (Figure 19) and least correlated with channel 5 ($r = -0.577$).

Correlation analysis indicated an inverse relationship between spectral reflectance in all four channels and percent perennial grasses. Percent cover by litter, which is moderately associated with percent tree cover, was negatively associated with the four spectral channels. This means as spectral brightness increases, due to decreased percent tree cover, percent cover by litter decreases.

Abiotic relationships with spectral data. Percent bare ground was found to be positively associated with channels 2, 3, and 4. Percent silt in the soil had a negative relationship with channel 2, and percent surface gravel had a positive relationship with channel 5. The soil erodibility (K) factor and the second spectral Principal Component (infrared energy) was found to have inverse relationships.

FIGURE 18. X-Y graph of the linear regression results for the relationship between TM channel 4 and percent tree cover.

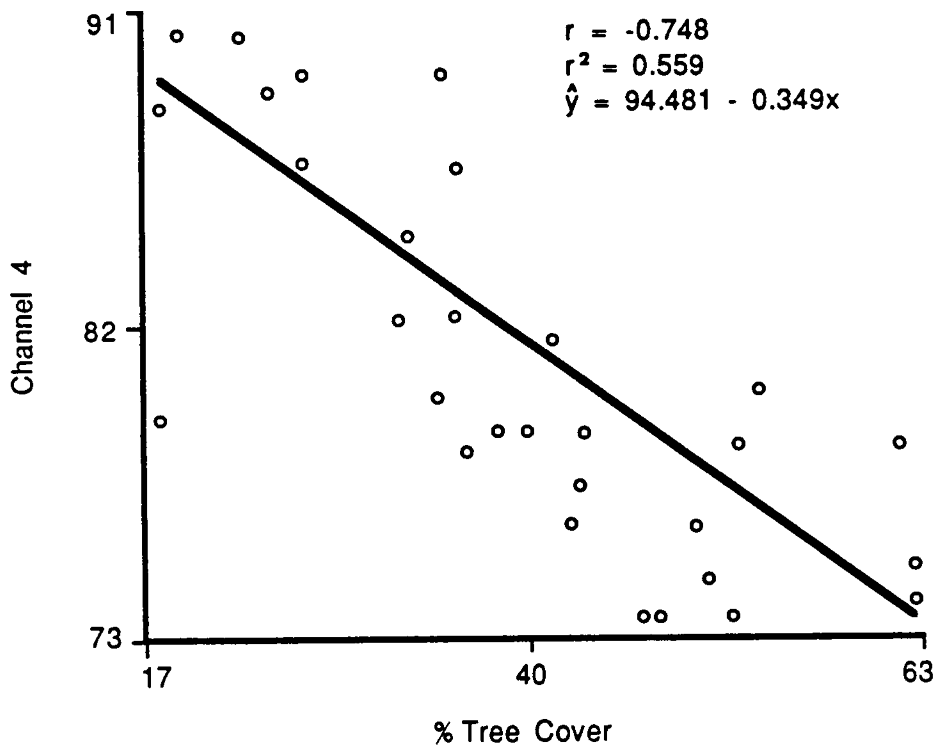
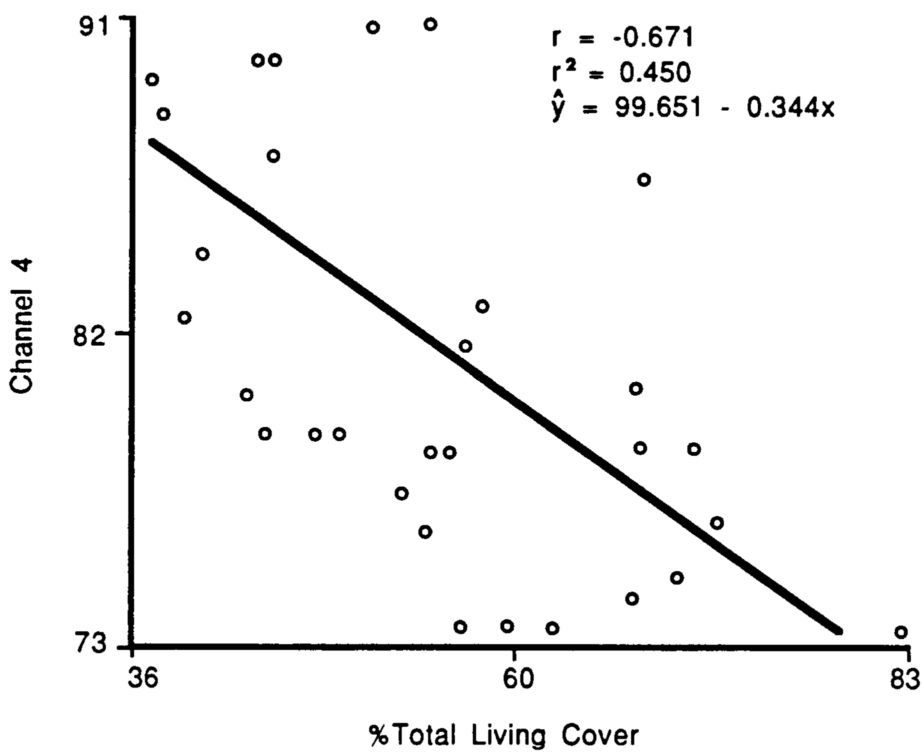

r = -0.748
r² = 0.559
ŷ = 94.481 - 0.349x
91
82
73
Channel 4
17
40
63
% Tree Cover

FIGURE 19. X-Y graph of the linear regression results for the relationship between TM channel 4 and percent total living cover.


r = -0.671
r² = 0.450
ŷ = 99.651 - 0.344x
91
82
73
Channel 4
36
60
83
%Total Living Cover

Environmental and Spectral Erosion Indices

Soil penetrability index. Though measurement of soil penetrability is not an absolute measurements of soil erosion, it may provide a relative index of soil loss between sites in close proximity to one another. Presumably, as the finer textured soil is eroded from the surface, concentration of gravel and rock fragments on the soil surface should increase. On relatively uniform sites, with respect to geographic location and environmental similarity, an index of soil depth might be established by pushing a sharp pointed steel rod into the ground to obtain an average soil penetration depth.

A negative relationship was found between percent cover by cryptogams and the soil penetration index. Several abiotic factors were found to be associated with soil penetration. Percent bare ground was positively associated, and both percent soil gravel and percent surface gravel were negatively associated with the soil penetrability index. Percent soil gravel was slightly more correlated than percent surface gravel ($r = -0.569$ and $r = -0.423$, respectively).

Soil value was also found to be positively correlated with soil penetration depth, indicating that darker soils, which were positively associated with increases in percent tree cover, recorded lower penetration depths than lighter soils which were positively associated with percent perennial grass cover and percent bare ground. The soil erodibility (K) factor and the soil penetration index were found to have a positive relationship.

Soil loss index. Using the string technique described in the methods section, two indices were generated. One erosion index is a relative estimate of total soil loss; the other is an estimate of the rate of soil erosion. Since measurement bench marks were established using soil depth along tree trunks, both indices are relative estimates of soil loss since tree establishment.

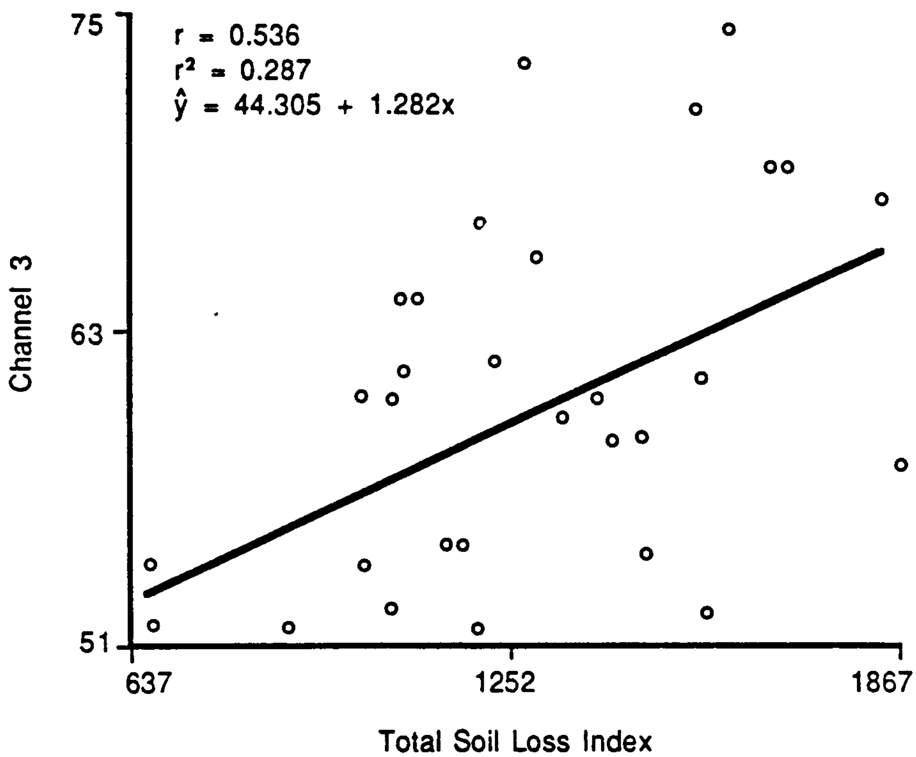
Correlation showed a negative relationship between soil penetrability measurements and the rate-of-erosion index. By excluding an outlying sample point, the correlation "r" value for the above relationship was improved from $r = -0.331$ to $r = -0.421$. The rate-of-erosion index was also negatively associated with the species richness index and percent cover by perennial forbs.

Percent soil gravel was found to be positively correlated with the rate-of-erosion index, and percent surface gravel was positively correlated with both the total-soil-loss index and the rate-of-erosion index. In offering a possible explanation for these three relationships, it should be known that percent silt was positively correlated with both percent soil gravel and percent surface gravel ($p = 0.565$ and $p = 0.449$, respectively) and percent clay was negatively correlated with both the gravel measurements ($p = -0.568$ and $p = -0.381$, respectively). The inherent erodibility of soil is positively influenced by percent silt and negatively influenced by percent clay. This may explain why sites with higher gravel content were positively associated with the erosion indices. Also, on sites where more soil is lost, one would expect to find more gravel exposed at the surface.

Both the rate-of-erosion and the total-soil-loss indices were negatively correlated with the soil erodibility (K) factor ($p = -0.379$ and $p = -0.317$, respectively). A possible explanation for these relationships may be that soils having a higher USLE erodibility (K) factor also are higher in both percent surface gravel and percent soil gravel. The gravel accumulating on the soil surface would retard erosion on these sites.

<u>Spectral relationships with erosion indices</u>. The total-soil-loss index was found to have a positive relationship with all four of the TM channels. The strongest relationship was with channel 3 ($r = 0.536$) (Figure 20). The weakest relationship was with channel 4 ($r = 0.436$). Channels 2, 3 and 5 were also found

FIGURE 20. X-Y graph of the linear regression results for the relationship between TM channel 3 and the total soil loss index.


r = 0.536
r² = 0.287
ŷ = 44.305 + 1.282x
75
63
51
Channel 3
637
1252
1867
Total Soil Loss Index

to have a positive relationship with the rate-of-erosion index. The strongest relationship was with channel 5 (r = 0.527) (Figure 21) and the weakest was with channel 2 (r = 0.362).

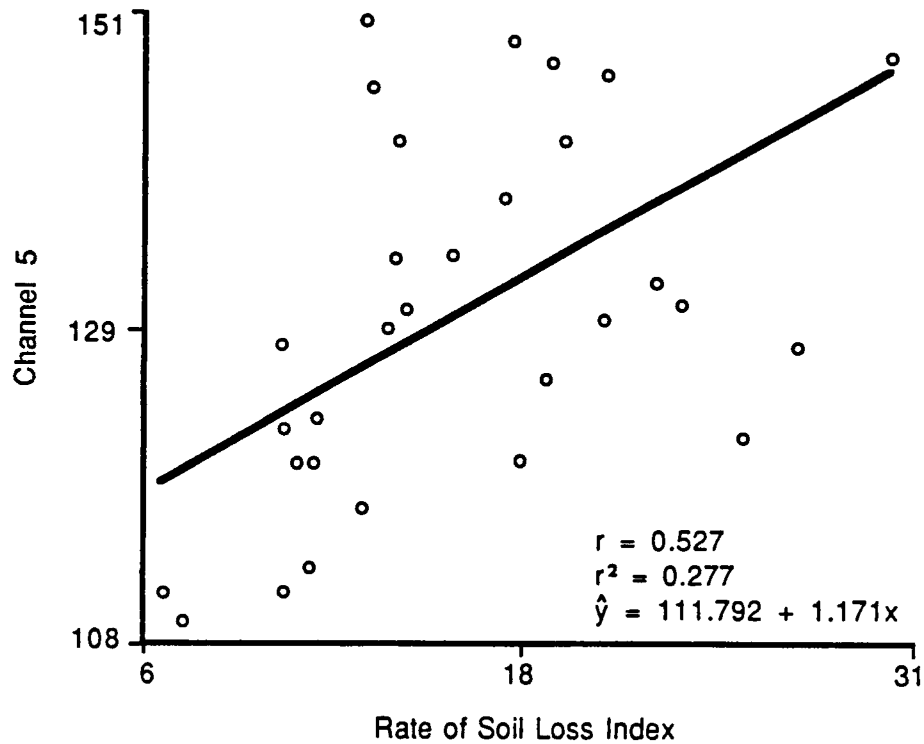
Multiple Regression Analysis

Multiple Regression Analysis was used for two purposes: 1) to determine the earth surface factors which explain the variability associated with the satellite spectral data, and 2) to determine which site factors are most associated with soil loss. Soil loss was regressed with three subgroups of site factors. These subgroups were: 1) the best combination of predictor variables from both the spectral and field data measurements, 2) the best predictors using only field measurements, and 3) the best predictors using only spectral data. The objective was to assess the relative contribution of information from ground, verses spectral date. To review the variables that were selected for use in the analysis see Appendix H.

Spectral Relationships with Field Factors

Individual channel relationships. To determine the earth surface factors affecting the spectral response, spectral channel values, the three Principal Components derived from the four TM channels, and field data were used as independent variables in Stepwise Multiple Regression Analysis. Table 14 shows the R and R^2 coefficients associated with the best possible combination of predictor variables. In reviewing Table 14, it is seen that dependent variables TM channels 2, 3, 4, and 5 were best described using the same three independent variables, percent tree cover, total-soil-loss index, and percent total nonliving material. It should be pointed out that percent total nonliving material did not

FIGURE 21. X-Y graph of the linear regression results for the relationship between TM channel 5 and rate of soil loss index.


151
129
108
Channel 5
6
18
31
Rate of Soil Loss Index
r = 0.527
r² = 0.277
ŷ = 111.792 + 1.171x

enter into the equation for channels 4 and 5. From the results, it appears that the independent variables explained the most variability in channel 4. It is interesting to note that only two variables were used to explain 68% of the variability in channel 4. It is also interesting that of the 20 possible independent variables used, the total-soil-loss index was selected as the second most important factor in explaining spectral variation. This indicates that satellite spectral information is sensitive to soil degradation within the pinyon-juniper woodlands. Since percent tree cover was the most important predictor in explaining spectral variation, satellite information could also be an effective means to study pinyon-juniper community. When multiple regression analysis was performed using percent cover by juniper (pinyon not included) as the dependent variable, and the two spectral Principal Components as independent variables, the results showed satellite data to explain a significant amount of the variability in cover by juniper. The first component explained 35% of the variability and the second added another 15%, for a total of 50%.

Principal Component relationships. Principal Components were derived using the four TM channels. Factor Analysis was used to transform the four channels into one Principal Component. Factor Analysis was again applied to the four channels to derive two Principal Components. The three spectral components were used as dependent variables in Stepwise Multiple Regression Analysis. Table 14 shows the field measurements most descriptive of variation in the three components. By combining all the spectral variability into a single component, the variability explained by field measurements improved only slightly. It is interesting to note that the best independent variables selected for the individual channels were also selected as best for describing the single component (R^2 = 0.70).

TABLE 14. Multiple regression results for the relationship between TM spectral data and field factors. (All "R" values are significant at $p \leq 0.05$.)

DEPENDENT VARIABLES:	INDEPENDENT VARIABLES:	R	R^2
Spectral Variables			
Channel 2	1. % Tree cover	-0.69	0.48
	2. Total soil loss (m^3/ha)	0.79	0.62
	3. % Total nonliving cover	0.82	0.67
Channel 3	1. % Tree cover	-0.65	0.42
	2. Total soil loss (m^3/ha)	0.80	0.63
	3. % Total nonliving cover	0.83	0.68
Channel 4	1. % Tree cover	-0.75	0.56
	2. Total soil loss (m^3/ha)	0.82	0.68
	3. % Total nonliving cover	Did not enter	
Channel 5	1. % Tree cover	-0.63	0.40
	2. Total soil loss (m^3/ha)	0.78	0.60
	3. % Total nonliving cover	Did not enter	
PCA (Single component)	1. % Tree cover	-0.70	0.49
	2. Total soil loss (m^3/ha)	0.82	0.67
	3. % Total nonliving cover	0.84	0.70
PCA 1 (Visible component)	1. % Tree cover	-0.59	0.35
	2. % Clay	0.74	0.54
	3. % Total nonliving cover	0.80	0.65
	4. Total soil loss (m^3/ha)	0.83	0.69
PCA 2 (IR component)	1. Soil loss rate (m^3/ha/yr)	0.59	0.34
	2. % Tree cover	0.72	0.51
	3. % Slope	0.78	0.61

Using the second set of Principal Components, the first component (interpreted as visible energy) was best described using percent tree cover, percent clay, percent total nonliving material and the total-soil-loss index. Using these four predictors, 69% of the variation was explained. The second component (interpreted as infrared energy) was best described using the rate-of-soil loss index, percent tree cover and percent slope. Using these three predictors, 61% of the variability was explained. It is believed that percent slope was selected as an important predictor, due to the variation in tree shadowing associated with changes in the slope gradient. It is also interesting to note that the rate-of-soil loss index was selected as the best variable for explaining variation in the second component.

In summary, results from multiple regression show that percent tree cover and the soil loss estimates were consistently the most important variables in explaining variation in the seven spectral measurements (4 TM channels and three Principal Components).

Soil Loss Relationships with Field and Spectral Factors

Field and spectral factors. Varying combinations of field and spectral data were used as predictors to explain variability in soil loss (Table 15). Both the total-soil-loss index (m^3/ha) and the rate-of-soil loss index (m^3/ha/yr) were used as dependent variables.

Table 15 lists the independent variables associated with the two soil loss indices. Interestingly, TM channel 5 was selected as the best describer of soil loss for both indices. In predicting the total-soil-loss index, only one variable qualified for entry into the prediction equation. Satellite TM channel 5 was found to explain 28% of the variability in the total-soil-loss index. In predicting

TABLE 15. Multiple regression results for the relationship of the two soil loss indices with various combinations of field and spectral factors. (All "R" values are significant at $p \leq 0.05$.)

DEPENDENT VARIABLES:	INDEPENDENT VARIABLES:	R	R^2
<u>Soil loss variables</u>			
<u>Both spectral and field variables</u>			
Total soil loss (m^3/ha)	1. Channel 5	0.53	0.28
	2. Frequency of Increasers	Did not enter	
	3. USLE (K) factor coefficients	" " "	
	4. Species richness (species/site)	" " "	
	5. % Total nonliving cover	" " "	
Soil loss rate (m^3/ha/yr)	1. Channel 5	0.53	0.28
	2. Frequency of Increasers	0.66	0.43
	3. USLE (K) factor coefficient	0.75	0.57
	4. Species richness (species/site)	0.79	0.62
	5. % Total nonliving cover	Did not enter	
<u>Using only field variables</u>			
Total soil loss (m^3/ha)	1. % Surface gravel cover	0.34	0.11
	2. Frequency of Increasers	Did not enter	
	3. Species richness (species/site)	" " "	
	4. % Rock cover	" " "	
	5. % Litter cover	" " "	
Soil loss rate (m^3/ha/yr)	1. % Surface gravel cover	0.48	0.23
	2. Frequency of Increasers	0.60	0.36
	3. Species richness (species/site)	Did not enter	
	4. % Rock cover	" " "	
	5. % Litter cover	" " "	
<u>Using two spectral Principal Components</u>			
Total soil loss (m^3/ha)	1. PCA 1 (visible energy)	0.46	0.21
	2. PCA 2 (infrared energy)	Did not enter	
Soil loss rate (m^3/ha/yr)	1. PCA 2 (infrared energy)	0.59	0.34
	2. PCA 1 (visible energy)	Did not enter	

the rate of soil loss, TM channel 5 again was most important in accounting for the variability. The frequency of increaser species was next in importance, followed by the USLE soil erodibility (K) factor and the species richness index. Percent total nonliving materials did not qualify for entry into the equation. The variables entering into the equation accounted for 62% of the variability in the rate-of-soil loss index.

Field factors. Using the field factors, and excluding the spectral variables, only a small portion of the variability in soil loss could be accounted for. Percent cover by surface gravel accounted for most of the variation in both indices. In predicting the total-soil-loss index, percent surface gravel was the only variable to enter into the equation. Its entry accounted for only 11% of the total variation. In predicting the rate-of-soil loss index, both percent surface gravel and the frequency of increaser species entered into the equation. These two variables accounted for 36% of the variability. The other three variables, species richness, percent rock, and percent litter, did not qualify for entry into the equation.

Spectral data. Finally, spectral data alone were used as independent variables for predicting both of the soil loss indices. Due to the multiple collinearity existing between TM channels, the two Principal Components were the only spectral variables used in the analysis. The first Principal Component (visible energy) was found to account for 21% of the variability in the total-soil-loss index. In this analysis, the second component (infrared energy) did not enter into the equation. The second Principal Component (infrared energy) accounted for 34% of the variability in the rate-of-soil loss index. The first component (visible energy) did not qualify for entry into the equation. It is interesting to note that a single spectral variable is accounting for approximately the same amount of variability in soil loss, as all the other field variables combined (Field variables 36%, spectral data 34%).

Judging from the Multiple Regression Analysis results, it would appear that TM spectral information can be used to account for a significant amount of the variability in soil loss within the pinyon-juniper woodlands. Under certain conditions, a single spectral channel may offer as much information as the combination of many field factors.

Universal Soil Loss Equation Estimates

USLE Coefficients

Values for all six USLE coefficients were derived, and an estimate of annual soil loss (A), in tons/acre/year was calculated for each site (Table 16). A summary of USLE coefficient data is given in Table 17.

One-Way Analysis of Variance was used to determine the statistical difference between spectral groups and the USLE factors. The results show no significant difference between the three groups for any of the USLE factors (Table 17).

The USLE cover management (C) factor was calculated for each site (Table 18). Cover estimates for each site were used to derive (C) factor estimates. Coefficients were determined using Table 10 on page 32 of the USDA Handbook Number 537 (USDA Science and Education Administration 1978). This table has been modified for application to permanent pasture, rangeland, and idle land.

The critical value derived from ANOVA indicates that at the $p \leq 0.05$ significance level, there was no difference in USLE (C) factor values calculated for each of the three spectral groups (Table 17). This indicates that according to

TABLE 16. Study site USLE soil erosion estimates. To determine whether a site is experiencing accelerated erosion, a soil erosion Tolerance (T) limit is listed. Sites where the USLE predicted (A) value exceeds the Tolerance limit (T) are marked with an asterisks.

SITE #:	EROSION ESTIMATE TONS/ACRE/YEAR (A)	TOLERANCE LIMIT (T)	ACCELERATED EROSION (A-T)
1	0.57	1.0	-0.43
2	0.54	2.0	-1.46
3	0.82	1.0	-0.18
4	0.99	1.0	-0.01
5	0.42	1.0	-0.58
6	0.69	1.0	-0.31
7	0.37	1.0	-0.63
8	1.95	1.0	0.95*
9	0.42	1.0	-0.58
10	0.50	1.0	-0.50
11	0.46	2.0	-1.54
12	0.79	1.0	-0.21
13	1.71	1.0	0.71*
14	1.17	1.0	0.17*
15	1.32	1.0	0.32*
16	0.86	1.0	-0.15
17	0.59	1.0	-0.41
18	0.83	1.0	-0.17
19	0.98	1.0	-0.02
20	0.94	1.0	-0.06
21	0.77	1.0	-0.23
22	0.27	1.0	-0.73
23	1.76	1.0	0.76*
24	0.43	1.0	-0.57
25	0.55	1.0	-0.45
26	0.49	2.0	-1.51
27	1.66	1.0	0.66*
28	1.71	1.0	0.71*
29	1.03	1.0	0.03*
30	0.97	1.0	-0.03

* Study sites where the USLE estimated soil erosion (A) value exceeded the soil tolerance (T) value. According to the USLE soil loss estimate, these sites are experiencing accelerated soil erosion and are eligible for soil conservation treatment.

TABLE 17. Calculated mean values for the USLE coefficients, spectral data, vegetation cover,and estimated soil loss index. The table also shows the Analysis of Variance probability results.

EROSION FACTORS:	Study Area	Group 1	Group 2	Group 3	ANOVA Prob.
USLE COEFFICIENTS:					
Rainfall (R)	40.00	40.00	40.00	40.00	1.00
Soil erosion (K)	0.22	0.22	0.21	0.22	0.94
Slope length/gradient (LS)	1.38	1.30	1.36	1.50	0.10
Ground cover (C)	0.07	0.06	0.09	0.07	0.23
Annual soil loss (A)	0.89	0.73	0.97	0.97	0.45
Accelerated soil loss (A-T)	-0.21	-0.37	-0.14	-0.13	0.64
SPECTRAL DATA:					
TM channel 2	53.33	46.00	50.30	57.70	0.05
TM channel 3	60.40	52.50	60.10	68.60	0.05
TM channel 4	80.70	74.80	79.40	87.90	0.05
TM channel 5	130.17	116.50	129.20	144.80	0.05
PCA 1 of 1	-0.15	-0.84	-0.37	0.77	0.05
PCA 1 of 2	-0.08	-0.96	-0.03	0.76	0.05
PCA 2 of 2	-0.16	-1.26	-0.30	1.07	0.05
VEGETATION COVER:					
% Total living cover	55.03	63.78	54.82	46.48	0.05
% Tree cover	39.46	47.31	43.04	28.02	0.05
% Understory cover	16.32	17.59	12.36	19.01	0.10
ESTIMATED SOIL LOSS:					
Total soil loss (m^3/ha)	1255.13	1051.20	1305.90	1408.30	0.05
Soil loss rate (m^3/ha/yr)	15.69	11.97	17.17	17.92	0.05

TABLE 18. USLE crop management (C) factor estimates for each study site.

STUDY SITE #	ESTIMATED (C) FACTOR	STUDY SITE #	ESTIMATED (C) FACTOR
1	0.09	16	0.09
2	0.04	17	0.04
3	0.09	18	0.09
4	0.06	19	0.09
5	0.04	20	0.09
6	0.06	21	0.09
7	0.04	22	0.04
8	0.13	23	0.09
9	0.04	24	0.04
10	0.04	25	0.04
11	0.04	26	0.04
12	0.09	27	0.09
13	0.09	28	0.09
14	0.09	29	0.09
15	0.14	30	0.09

the USLE (C) factor, there are no significant differences in vegetation cover types between the three spectral groups.

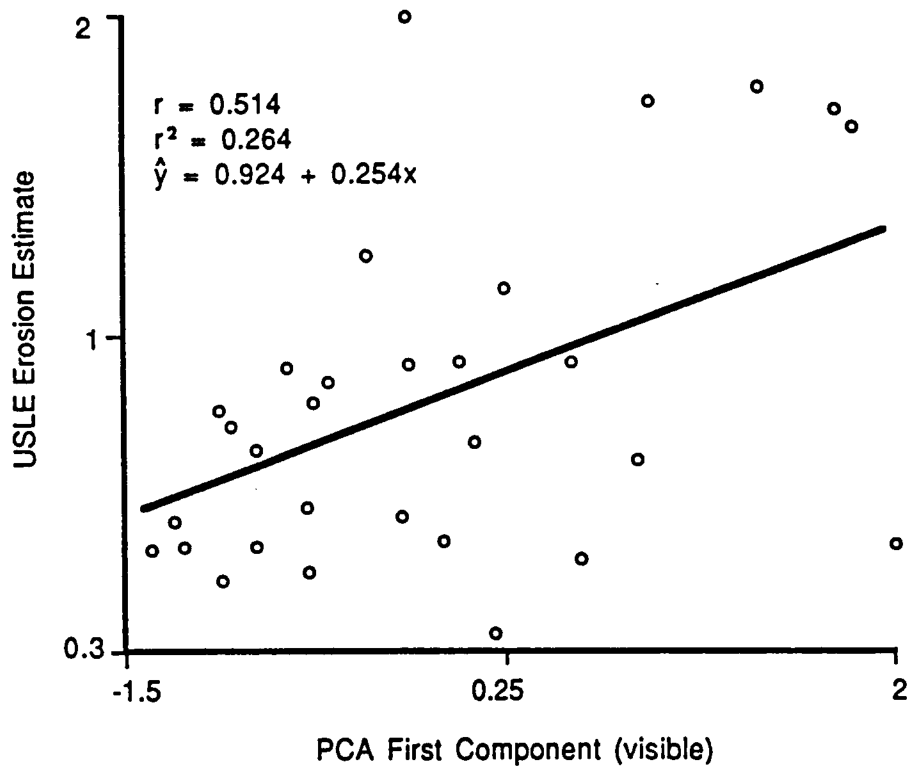
Estimates of annual soil loss (A) derived using the USLE show the average rate of erosion within the study area to be 0.89 ton/acre/year. The estimates show Group 1 to have an average soil loss of 0.73, Group 2 a lose of 0.97, and Group 3 also a lose of 0.97 tons/acre/year. The ANOVA results show there is no significant difference in soil loss (based on USLE estimates) between any of the groups.

When the annual soil loss (A) estimate is subtracted from the soil loss tolerance limit (T), the results show the study area average annual soil loss to exceed (T) by 0.21 tons/acre/year (Table 17). The (A) - (T) estimates for each group are as follows, Group 1 = 0.37, Group 2 = 0.14, and Group 3 = 0.13. These results would suggest that under Soil Conservation Service (SCS) regulations, because the erosion estimates are so low, none of the study sites would qualify for soil erosion conservation programs.

Relationship of USLE Erosion Estimate to Other Factors

Correlation analysis shows the USLE annual soil loss (A) estimate is positively correlated with the first Principal Component (visible energy) ($r = 0.514$, $r^2 = 0.264$). Interpreted, this means as the annual rate of erosion on a site increases, the visible light reflected from the soil surface increases (Figure 22). This relationship suggests that in spite of grossly under-estimating soil loss on the pinyon-juniper sites, 26% of the variability in the USLE (A) estimates is accounted for in TM spectral data. It should be pointed out that the USLE (A) estimates shared no significant relationships with erosion estimates made using the string technique. When the USLE (A) estimate was regressed with field data,

FIGURE 22. X-Y graph of the linear regression results for the relationship between USLE erosion estimate and PCA first component(visible energy).



r = 0.514
r² = 0.264
ŷ = 0.924 + 0.254x
USLE Erosion Estimate
2
1
0.3
-1.5
0.25
2
PCA First Component (visible)

percent total nonliving cover was found to correlate the highest with the estimate ($r = 0.669$) (Figure 23). Other factors sharing significant relationships with the USLE (A) value were percent slope ($r = 0.554$), percent litter ($r = -0.415$), percent cover by decreaser species ($r = 0.346$), and percent total living cover ($r = 0.319$). Most of the variables listed above were used in deriving the USLE coefficients, so significant relationships with the USLE erosion estimates are not surprising.

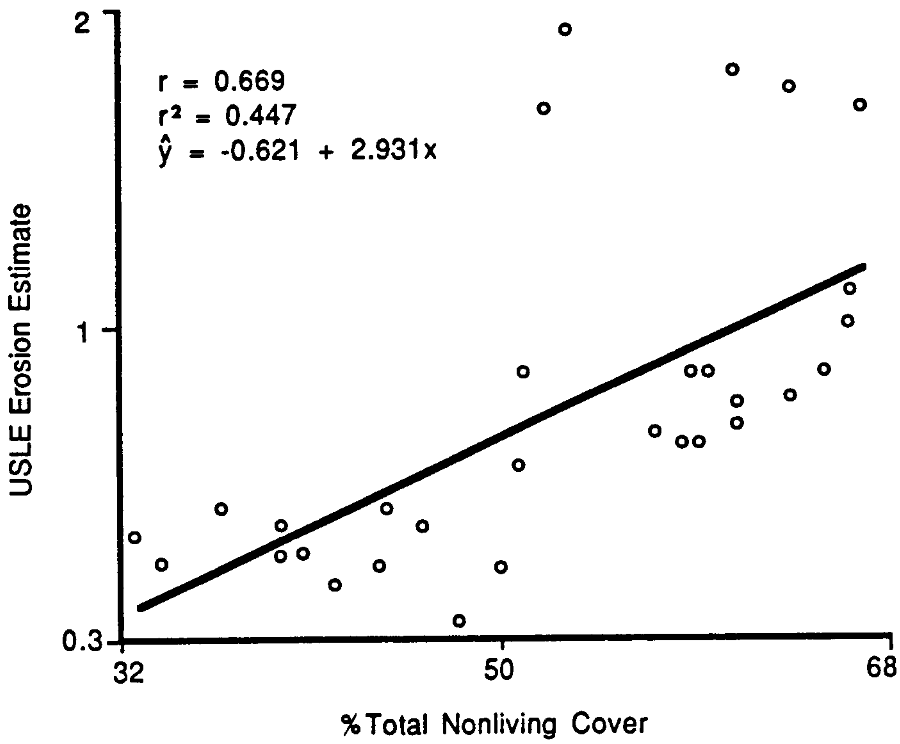
Contradicting Results

While gathering field data, indications of recent soil erosion were prevalent throughout the area. Examples of erosion indicators observed were sheet erosion rippling, rilling, gullying, accumulation of debris behind obstacles, rocks overturned, pedestalling, root exposure, and others. The obvious signs of accelerated soil loss on the study sites suggest that results obtained from the USLE are unreliable, especially when other field measurements indicate significantly higher rates of erosion throughout the study area.

Spectral data and soil erosion. Table 17 shows average spectral digital numbers for each group, for the four channels and the three Principal Components. Results from ANOVA show significant spectral differences between the three groups. Spectral differences do not prove accelerated soil erosion, but since correlation analysis indicates a positive relationship between spectral variance and the soil loss indices, and since ANOVA shows significant differences in erosion exists between the three spectral groups, one might confidently say, TM spectral data are sensitive to soil erosion variance within the pinyon-juniper woodlands.

Vegetation cover. Table 17 also shows significant differences between the three groups, with respect to vegetation. The results show that percent total

FIGURE 23. X-Y graph of the linear regression results for the relationship between USLE erosion estimate and percent total nonliving cover.



r = 0.669
r² = 0.447
ŷ = -0.621 + 2.931x
USLE Erosion Estimate
2
1
0.3
32
50
68
%Total Nonliving Cover

living cover occupied 55% of the study area. Percent tree cover dominates 39% of the 55%, and percent understory species occupied the remaining 16%. The ANOVA results show there is significant differences between the three spectral groups and the three vegetation cover factors listed in Table 17. It is interesting to note these differences because according to the USLE crop management (C) factor, there are no differences between the three groups, with respect to the vegetation cover component.

Estimated soil loss. Estimates of annual soil loss (A) derived using the USLE (refer back to Table 16) show few of the sites exceeding the soil loss tolerance (T) value. Erosion measurements made during this study, using the string method, indicate substantial soil loss on all study sites (Table 19). Referring back to Table 12, it is seen that for Groups 1-3, the adjusted[1] estimated average loss of soil in cubic meter/hectare/year is 6.1, 9.4, and 12.9, respectively. Table 19 shows the erosion estimates converted to tons/acre/year. The adjusted average estimates in tons/acre/year for Groups 1-3 are 13.4, 21.7, and 38.0, respectively. Table 19 also shows the adjusted minimum and maximum estimates to be 6.5 for site 8, and 51.8 for site 24, respectively. The average adjusted soil loss estimate for the study area is 24.4 tons/acre/year.

The ANOVA results also indicate statistically significant differences in soil losses between the three groups (Table 17). The differences are substantial, with a range of 24.6 tons/acre/year between the means of Groups 1 and 3.

Substantiating results. Results from the string technique show the adjusted rate of soil loss to be 1.45 mm/yr. Estimates for spectral Groups 1-3 are 1.12, 1.55, and 1.67 mm/yr, respectively. McCord (1987) used exposed juniper tree roots

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[1]This estimate has been adjusted to account for the area occupied by pinyon and/or juniper trees. (Adjusted estimate = erosion estimate - % cover by juniper)

TABLE 19. Soil erosion estimates for each study site. The estimates were made using the string technique.

SITE #:	TOTAL LOSS TONS/ACRE	ADJUSTED TOTAL LOSS TONS/ACRE	RATE OF LOSS TONS/ACRE/YEAR	ADJUSTED RATE OF LOSS TONS/ACRE/YEAR
GROUP 1				
1	2,152.0	1,129.8	21.2	11.1
2	2,762.0	1,574.3	27.1	15.5
3	2,078.0	783.4	35.3	13.3
4	1,458.0	721.7	14.4	7.1
5	2,847.0	2,363.0	35.7	29.6
6	3,393.0	1,951.0	38.5	22.1
7	2,195.0	1,064.6	24.4	11.8
8	1,328.0	703.8	12.2	6.5 MINIMUM
9	1,968.0	997.8	20.0	10.1
10	1,850.0	693.8	18.3	6.9
$\bar{x}$ =	2,203.1	1,198.3	24.7	13.4
σ =	637.9	579.8	9.2	7.4
GROUP 2				
11	3,587.0	2,331.6	45.0	29.3
12	2,859.0	1,115.0	39.3	15.3
13	2,653.0	1,591.8	28.8	17.3
14	2,808.0	1,881.4	26.3	17.6
15	2,883.0	1,729.8	47.1	28.3
16	2,796.0	1,342.1	41.2	19.8
17	3,670.0	2,348.8	37.5	24.0
18	2,549.0	1,198.0	33.8	15.9
19	3,323.0	2,073.6	34.6	21.6
20	2,459.0	1,406.5	48.3	27.6
$\bar{x}$ =	2,958.7	1,701.9	38.2	21.7
σ =	422.9	448.9	7.5	5.3
GROUP 3				
21	4,842.0	3,287.7	46.0	31.2
22	2,785.0	1,788.0	35.7	22.9
23	4,101.0	2,993.7	44.1	32.2
24	2,785.0	1,810.3	79.7	51.8 MAXIMUM
25	4,689.0	3,573.0	61.3	46.7
26	5,149.0	3,727.9	59.8	43.3
27	4,931.0	3,673.6	62.4	46.5
28	4,242.0	3,359.7	46.7	37.0
29	5,341.0	4,417.0	57.3	47.4
30	3,059.0	1,979.2	33.0	21.4
$\bar{x}$ =	4,192.4	3,061.0	52.6	38.0
σ =	983.5	908.1	14.2	10.8
TOT. $\bar{x}$ =	3,118.1	1,987.1	39.4	24.4
TOT. σ =	1,085.0	1,031.0	15.2	13.0

and growth ring analysis to estimate rate of erosion on a drainage in northern Arizona. The author estimated that juniper trees in his study area were approximately 650 years old. The hillslope where McCord's tree root samples were taken was eroded to an underlying Cretaceous sandstone and siltstone (McCord 1987). McCord estimated that over the last 650 years, the average rate of soil erosion from his study sites is 0.33 mm/yr. It is not surprising that his estimate is lower than the estimates obtained in this study. As mentioned earlier, it is believed that measurements taken next to the tree trunk will underestimate erosion because of soil protection provided by the tree canopy and ground litter. Secondly, soils in McCord's study have been invaded by juniper for at least 650 years, while in this study, invasion has been relatively recent (less than 100 years). On McCord's sites, erosion rates have been retarded for hundreds of years by rock coverings and bedrock outcrops.

It is believed that the 0.33 mm/yr erosion rate measured on McCord's old sites, as opposed to the 1.44 mm/yr rate measured in this study, lends strength to the hypothesis that erosion rates on pinyon-juniper sites are greatly accelerated upon initial tree invasion. It is also believed that erosion estimates derived using the string technique are more accurate than those derived using the Universal Soil Loss Equation (USLE). Estimates derived from the USLE were surprisingly low and showed little variation in erosion rates between sites. Field observations would lead one to believe that significant differences in soil erosion existed between study sites and string measurements substantiate the observation. As a result of the findings in this study, it is felt that reconsideration should be given to the use of USLE on pinyon-juniper woodlands. Even the use of USLE estimates as an index for site comparison purposes should be questioned, especially if sites are located within the same general area.

DISCUSSION

Soil Erosion Differences Between Groups

Because percent cover by pinyon and/or juniper trees was found to be greatest on sites assigned to Group 1 and least on sites assigned to Group 3, it was originally believed that the oldest invasions were probably associated with Group 1. Believing that older invasions would mean increased time for accelerated soil erosion, it was thought that soil losses would be most severe on Group 1 sites and less severe on Group 3 sites. Surprisingly, string measurements of erosion indicated the opposite was true (Table 12). At first this was somewhat confusing, but after studying the data, it is believed an answer to the question may have been discovered.

Figures in Table 12 indicate there is less surface rock found on Group 3 sites (4.8%) than on Group 1 sites (9.0%). There is also significantly more bare ground associated with Group 3 than with Group 1. Also, average depth of soil penetration is shown to be slightly deeper on Group 3 sites. (Although ANOVA does not show the depth difference to be significant at $p \leq 0.05$, field observations tend to favor the notion that Group 3 soils are generally deeper.) In comparing biotic differences (Table 7), sites for Group 1 have a greater percent cover by juniper and a greater percent cover by total living vegetation (predominately pinyon-juniper). Correlation results also indicate that with increases in percent tree cover, soil penetration depth decreases. Correlation results also suggest that as percent tree cover increases, percent understory cover decreases. Interestingly, tree ring counts show no significant difference in the age of the trees found on sites for any of the three groups. This finding changed the original idea that sparser populated pinyon-juniper stands are indicative of more recent site invasion by trees.

Although there is no conclusive evidence to substantiate the notion, it is believed that the difference in total soil loss and rate of soil loss for the three groups are primarily associated with site characteristics, as opposed to varying stages of ecological succession between groups. It may be that slightly deeper soils allow for increased plant competition which might explain the less successful invasion of pinyon-juniper onto Group 3 type sites. The increased rock associated with Group 1 may indicate that soils are shallower on these sites. If this is true, erosion is probably limited by rock fragments and bedrock outcrops. Sites with deeper soils and invading juniper may show increased loss of soil simply because erosion is unrestrained by surface rock fragments and because erosion on deeper soils can proceed downward to greater depths. Sites with shallow soils are probably more susceptible to tree invasion due to the ability of pinyon-juniper to root deeply in rock crevices and to compete on sites with harsher environmental conditions. Also, because there is usually less understory on shallow soils, the probability of fire is lessened.

Universal Soil Loss Equation Results

Regardless of the reason for the differences in soil loss between groups, significant differences were detected using satellite spectral data. Coefficient values and estimates from USLE indicate there are no significant differences between groups, or even between individual sites. In light of estimates obtained using the string technique, and assuming the technique is sensitive to varying degrees of soil loss, it seems that USLE lacks sufficient sensitivity to accurately provide erosion estimates within the study area for the pinyon-juniper woodlands.

Judging from results of this study, USLE estimates appear to be inadequate for predicting soil loss on pinyon-juniper sites. It is felt that further research is needed before estimates of erosion from USLE on pinyon-juniper stands can be used with confidence.

Satellite Spectral Results

As reported earlier, spectral data were most sensitive to variations in percent tree cover and variation in degree of soil erosion. From this study it was determined that sensitivity to various environmental features may be increased or decreased depending on the size of the area used to generate spectral signatures, and depending on the way spectral signatures are grouped. In this way, satellite data can be used to study general relationships over broad areas, or fine tuned to provide more specific information for smaller study areas.

At the onset of this study, efforts were made to maintain a certain degree of control over such factors as percent slope and aspect. Because study sites were located within a relatively small study area, it was not surprising that insignificant differences for the biotic and abiotic factors were common between the three pinyon-juniper spectral groups. On the other hand, it was encouraging to note that in spite of the relatively homogeneous environment, satellite TM information was sufficiently sensitive to detect 40 pinyon-juniper cover types within the study area. Though much of the variation between the 40 types may seem unimportant from a management standpoint, the fact that such information can be derived should be of great interest to those desiring to better understand environmental relationships within the pinyon-juniper woodlands. The subtle variation detected from satellite could be used to better understand nutrient, moisture, structure variation, etc., within the pinyon-juniper community type.

Data summary tables (Tables 7 and 12) show small differences between the three spectral groups. In this study, some environmental differences were too subtle to be detected using conventional methods for monitoring environmental condition. Though ecological change may be subtle, the response to that change can often be dramatic. This is evidenced in the fact that within a relatively homogeneous environment, significant differences in soil erosion were observed. Using the USLE, these differences were not detected. Based on results from this study, satellite information appears to possess the sensitivity required to detect subtle variation associated with significant ecological differences.

Satellite TM data contains important information regarding soil erosion differences within pinyon-juniper woodlands. It is believed that greater soil erosion information could be obtained if the study technique were applied over a larger study area. Though greater environmental diversity will be incurred, it seems likely that with adequate research, much of the diversity can be accounted for. Conventional methods for modelling soil erosion are very impractical when one considers the task of applying an erosion model to millions of acres of native rangeland. In considering the USLE, it is nearly an impossible feat to accurately estimate percent slope and slope length, and to determine the cover factor over large areas. To rationalize that general estimates are adequate for the study is to say also that poor or inaccurate, information is good enough. Unfortunately, many resource managers are forced to work with such information.

With the advent of Landsat satellite and digital terrain data, it is probable that improved methods for modelling soil loss can be developed. In this study, satellite data were successfully used to accurately delineate relatively subtle and pertinent vegetation and site differences. Study results indicate that satellite information is more sensitive to vegetation differences than the USLE (C) factor, which suggests that TM data can be used to accurately delineate vegetation types based on criteria pertinent to the USLE (C) factor. Regression Analysis results indicate that even within a relatively homogeneous vegetation type, satellite data explained more of the variability in soil erosion, within the study area, than all of the other field measurements combined. Using TM channel 5, 28% of the variability in soil erosion was accounted for (R = 0.53).

Erosion Modelling in the Future

Soil erosion estimates on native rangelands will improve as the relationships between erosion and environmental factors are better understood. Although this kind of information will improve prediction abilities, it will be of little use if, when applied to native rangelands, the information going into the model is overly generalized. Common sense would suggest that future erosion models for rangelands should be developed and calibrated using information offering the greatest potential in terms of accuracy over large areas. In the past, some models have been developed for use on small plot watersheds, and later have been applied to large areas where the models fail to account for other factors effecting soil loss. It is my belief that satellite data, coupled with digital terrain data, offer the greatest potential for inventory of vast land acreage. Future erosion models for rangelands should be designed which employ the use of satellite remotely sensed data.

This study is but a small beginning. Future studies should be implemented which concentrate on larger areas and the integration of other forms of information. Satellite information should be used to identify environmental variability and studies should be conducted to understand the factors contributing to that variability. Appropriate adjustments, with regard to the digital processing methods, should then be made which accentuate information pertinent to the study goal. To improve the accuracy of the satellite spectral erosion models, the following developments are necessary:

1. Methods for estimating soil loss and soil loss rates on a site must be developed so that satellite spectral responses can be correlated with soil erosion. The string technique developed for this study should be tested for accuracy. Other erosion models will be needed on grass and shrublands.
2. Ancillary data types which are descriptive of soil loss on rangelands must be determined and included in the prediction model. Data types might include
   a. Digital Elevation Models (DEM) (Using these data, elevation, slope gradient, and slope aspect can be estimated.)
   b. Precipitation data
   c. Soil types and the inherent erodibility of the soil.
3. The model needs to be applied over larger areas where increased diversity of topography, soils, and vegetation will be encountered.

In many states, data bases are already being compiled. Information such as soil maps, which are being stored in a GIS format, will be useful. There is little doubt that future resource management planning will depend heavily on spatially oriented digital data. Plans should be made now to prepare for future demands which will be placed on resource managers and on the natural resources for which they are responsible.

CONCLUSIONS

The analysis and interpretation of the data used in this study have lead to the following findings:

1. TM satellite spectral data are sensitive to variation in soil erosion within some pinyon-juniper woodlands.
2. TM satellite spectral data are more sensitive to variation in soil erosion than the USLE.
3. TM satellite spectral data are more sensitive to variations in percent cover of vegetation than the USLE crop management (C) factor.
4. TM channel 5 accounted for more variability in soil erosion than all the field measurements combined.
5. TM channel 4 was highly correlated with percent cover of pinyon-juniper ($r = 0.748$, $r^2 = 0.560$).
6. USLE estimates of soil erosion on the pinyon-juniper woodlands did not correlate with other erosion estimating or indexing methods used in the study.
7. USLE estimates were much lower than erosion estimates derived using other methods.
8. Erosion rate estimates indicate that in the past there has been highly accelerated soil loss from the pinyon-juniper sites investigated in this study.

9. Findings of this study, coupled with other results, are compatible with the theory that soil loss is greatly accelerated at time of tree invasion and gradually declines as stand maturity is reached.
10. Findings indicate that site differences in percent cover by juniper are more attributable to variance in site characteristics, than to the length of time since initial invasion by the trees.
11. Good results were derived using a new on-the-ground estimate of total soil loss and rate of soil loss since tree establishment.

Based on the above findings, the following conclusions were derived:

1. TM satellite spectral data can be used to develop a prediction model for estimating soil erosion on pinyon-juniper woodlands.
2. TM satellite spectral data can be used to predict the USLE crop management (C) factor for pinyon-juniper woodlands.
3. For the study area, USLE is not the appropriate model for predicting soil loss on pinyon-juniper woodlands.

It is hoped that findings from this study will encourage natural resource managers to reconsider present methods of monitoring site retrogression in pinyon-juniper woodlands. Given the large area occupied by pinyon and juniper in the western United States, deriving accurate estimates for coefficients used in traditional erosion models is impractical, if not impossible. Considering the results derived from the USLE in this study, it is believed effort would be better spent developing a erosion model which incorporates the use of satellite spectral data, coupled with other existing information such as digital elevation data. With such information now available, it is certain that improved methods for inventory, monitoring, and research of pinyon-juniper communities are possible and can be developed.

APPENDIX A

PLANT SPECIES USED TO DEVELOP AN "EROSION" INDEX

Increaser Species

Agropyron cristatum (Crested wheatgrass)

Agropyron intermediate (Intermediate wheatgrass)

Bromus tectorum (Cheatgrass)

Cynoglossum officinale (Houndstongue)

Lactuca serriola (Prickly lettuce)

Poa pratensis (Kentucky bluegrass)

Verbascum thapsus (Flannel mullein)

Decreaser Species

Agropyron spicatum (Bluebunch wheatgrass)

Artemisia spinescens (Bud sagebrush)

Artemisia tridentata (Big sagebrush)

Bromus inermis (Smooth brome)

Cercocarpus montanus (Birchleaf mountain mahogany)

Cryptogams (Mosses and Lichens)

Ephedra viridis (Green mormontea)

Gilia aggregata (Skyrocket gilia)

Oryzopsis hymenoides (Indian ricegrass)

Penstemon spp. (Penstemon)

Purshia tridentata (Antelope bitterbrush)

Senecio multilobatus (Lobeleaf groundsel)

Sitanion hystrix (Bottlebrush squirreltail)

Stipa comata (Needleandthread)

Note: Species were classified as either Increaser or Decreaser species according to their anticipated response to increased site degradation.

APPENDIX B

CONVERSION OF STRING MEASUREMTNTS OF SOIL LOSS TO VOLUMETRIC AND WEIGHT ESTIMATES

As explained in the METHODS section of the dissertation, string to soil surface measurements were taken at 20 cm intervals along the stretched string. (i.e., If the interspace between two trees is 3 m, then there will be 15 + 1 = 16 measurements ((3 m * 100 cm/m) / 20 cm/interval = 15 intervals + 1 end point = 16 points)) Once measurements are recorded, the average depth from the soil surface up to the string can be calculated (Figure 24).

<u>Step 1</u>

Using measurements shown in Figure 24,

Average Depth = 6 + 6 + 7 + 8 + 9 + 10 + 11 + 12 + 13 + 12 + 11 + 10 + 9 + 8 + 7 + 5 = 144 cm / 16 points = <u>9 cm/point</u>

These measurements show the average difference in the soil depth between the tree canopy interspace and the soil line at the tree base to be 9 cm. The following will explain the steps in converting the 9 cm measurement into a volumetric index, and finally into a soil weight loss index.

If one assumes the average soil loss is relatively uniform throughout the surrounding area (i.e., an area equal to one hectare (100 m x 100 m)), a volumetric estimate of soil loss within the tree interspace can be derived (Figure 25).

<u>Step 2</u>

<u>Conversion of the average soil difference estimate into a cubic meter estimate</u>

Since it is known that 100 cm is equal to 1 m,

9 cm of soil loss * 100 cm/m * 100 cm/m = <u>90,000 cm^3/m^2</u>.

FIGURE 24. Diagram of string stretched between two trees and 16 depth measurements taken at 20 cm intervals.

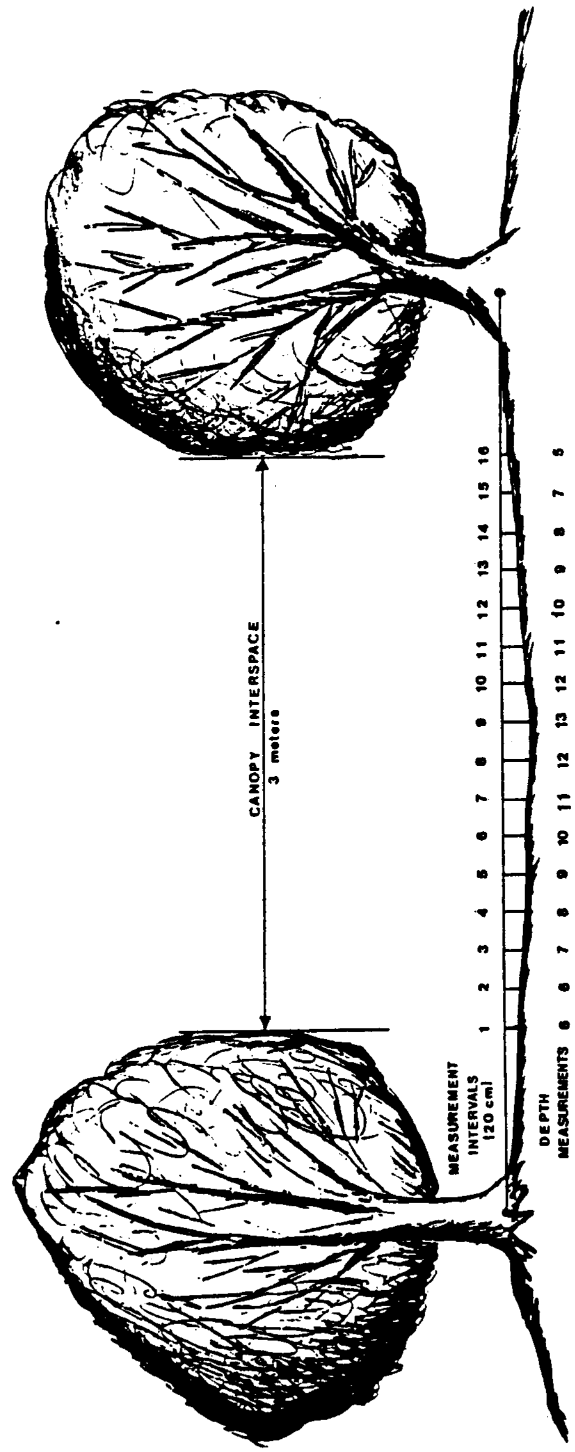
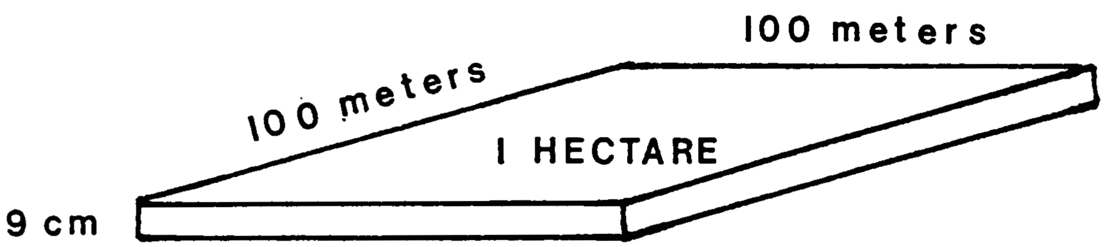

CANOPY INTERSPACE
3 meters
MEASUREMENT INTERVALS (20 cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DEPTH MEASUREMENTS (cm)
6 6 7 8 9 10 11 12 13 12 11 10 9 8 7 5

FIGURE 25. Diagram depicting volumetric measurement of 9 cm of soil loss on a 100 m x 100 m (one hectare) square area.


100 meters
100 meters
1 HECTARE
9 cm

Step 3

Conversion from cubic centimeters of soil loss per square meter to cubic centimeters of soil loss per hectare

Since it is known that a hectare is equal to 100 m x 100 m = 10,000 m^2/ha,

$$\mathbf{90{,}000\ cm^3/m^2 \ast 10{,}000\ m^2/ha = \underline{900{,}000{,}000\ cm^3/ha}.}$$

Step 4

Conversion from cubic centimeters per hectare to cubic meters per hectare

Since 100 cm/m * 100 cm/m * 100 cm/m = $\underline{1{,}000{,}000\ cm^3/m^3}$,

then,

$$\mathbf{900{,}000{,}000\ cm^3/ha \ /\ 1{,}000{,}000\ cm^3/m^3 = \underline{900\ m^3/ha}.}$$

Step 5

Conversion of volumetric estimate into a weight estimate

For illustration purposes, it will be assumed that the average bulk density of the soil is 1.5 g/cm^3. Since there is 1,000,000 cm^3/m^3,

$$\mathbf{1.5\ g/cm^3 \bullet 1{,}000{,}000\ cm^3/m^3 = \underline{1{,}500{,}000\ g/m^3}}$$

and because, in this example there are 900 m^3/ha of soil loss,

$$\mathbf{1{,}500{,}000\ g/m^3 \bullet 900\ m^3/ha = \underline{1{,}350{,}000{,}000\ g/ha}}$$

and since there is 1,000 g/kg,

$$\mathbf{1{,}350{,}000{,}000\ g/ha \ /\ 1{,}000\ g/kg = \underline{1{,}350{,}000\ kg/ha}.}$$

Step 6

To convert from kilograms per hectare to pounds per acre

1,350,000 kg/ha * 0.892 = 1,204,200 lbs/acre

Since there are 2,000 lbs/ton,

1,204,200 lbs/acre / 2,000 lbs/ton = 602.1 tons/acre.

Step 7

Determining the annual rate of erosion index value

If the average age of the trees used for the string measurement was found to be 100 years, then

602.1 tons/acre / 100 yrs = 6.021 tons/acre/yr.

APPENDIX C

DATA MEASUREMENTS FOR EACH VARIABLE FROM EACH STUDY SITE

STUDY SITE #	CHAN2	CHAN3	CHAN4	CHAN5	1COMP2	2COMP2	1COMP1
1	45	52	73	111	-0.67	-1.58	-1.52
2	46	54	77	112	-0.11	-1.77	-1.20
3	47	54	75	122	-1.07	-0.31	-1.03
4	47	51	74	108	-0.02	-2.32	-1.47
5	45	51	78	123	-1.51	0.12	-1.10
6	47	52	76	120	-0.95	-0.58	-1.10
7	46	51	73	116	-1.06	-0.92	-1.40
8	46	53	73	110	-0.32	-1.91	-1.45
9	46	53	76	123	-1.34	-0.02	-1.05
10	45	54	73	120	-1.39	-0.27	-1.26
11	50	60	80	135	-0.94	0.89	-0.17
12	48	58	78	129	-1.03	0.38	-0.56
13	51	60	81	120	0.78	-1.58	-0.39
14	52	60	82	129	0.16	-0.37	-0.11
15	50	62	79	130	-0.38	0.08	-0.24
16	50	61	78	131	-0.64	0.31	-0.30
17	51	61	78	129	-0.27	-0.14	-0.29
18	51	59	80	126	0.04	-0.59	-0.35
19	49	59	79	130	-0.79	0.33	-0.41
20	51	61	79	133	-0.58	0.44	-0.17
21	56	68	84	138	0.77	0.10	0.66
22	55	64	87	142	0.13	0.90	0.67
23	57	66	87	135	1.33	-0.52	0.70
24	56	64	82	148	-0.68	1.85	0.63
25	62	75	91	147	2.06	0.17	1.71
26	57	69	90	148	0.53	1.26	1.21
27	60	72	89	143	1.70	0.01	1.33
28	61	72	91	147	1.65	0.42	1.54
29	58	69	88	149	0.45	1.34	1.19
30	55	67	90	151	-0.27	2.07	1.09

Note: Explanation of abbreviations associated with each variable.

CHAN2-5 - TM satellite channel raw data values
1COMP2 - First Principal Component of the two components generated.
2COMP2 - Second Principal Component of the two components generated.
1COMP1 - Only one Principal Component was generated.

STUDY SITE #	JUOS	PIED	TLIVG	UNSTY	PGRAS	AGRAS	SHRUB	PFORB
1	41.3	5.0	57.4	11.1	0.9	1.0	0.1	4.4
2	35.0	8.0	54.4	11.4	0.8	8.3	0.3	0.9
3	47.5	14.8	69.7	7.4	0.9	3.2	0.0	0.1
4	50.5	0.0	67.0	16.5	2.9	8.8	1.1	2.8
5	17.0	0.0	56.2	39.2	21.1	0.9	11.2	0.4
6	31.5	10.0	70.8	29.3	12.5	0.8	10.8	1.6
7	36.0	9.0	60.1	15.1	1.3	1.3	0.2	0.4
8	38.0	9.0	62.8	15.8	2.9	0.4	4.5	6.2
9	23.8	23.0	56.0	9.2	0.6	0.0	0.0	0.1
10	62.5	0.0	83.4	20.9	1.6	6.2	6.6	0.8
11	30.0	2.0	45.2	13.2	2.2	2.7	2.7	1.3
12	52.0	9.0	66.8	5.8	0.4	1.1	1.1	1.2
13	40.0	0.0	55.1	15.1	5.0	5.3	1.0	2.3
14	16.0	15.0	42.3	11.3	3.0	0.0	2.2	1.6
15	39.0	0.3	46.8	7.5	0.3	2.9	0.1	0.2
16	45.0	7.0	69.3	17.3	3.5	1.4	0.5	0.0
17	31.0	5.0	57.3	21.3	1.1	2.7	2.1	13.3
18	50.0	3.0	65.8	12.8	1.0	1.8	0.8	0.2
19	25.5	12.0	49.2	11.7	1.9	2.4	0.8	0.4
20	42.8	0.0	50.4	7.6	0.4	0.5	2.2	0.0
21	31.3	0.8	42.6	10.5	2.9	2.2	0.5	3.1
22	35.8	0.0	64.8	29.0	11.6	2.3	9.3	0.4
23	27.0	0.0	42.6	15.6	4.8	4.8	0.3	1.5
24	35.0	0.0	56.9	21.9	6.7	3.3	4.2	0.5
25	22.8	0.0	52.0	29.2	20.0	3.4	2.5	0.6
26	26.8	0.8	42.0	14.4	3.3	4.7	0.4	1.1
27	25.5	0.0	35.8	10.3	2.8	3.7	2.3	1.3
28	20.8	0.0	48.8	28.0	21.7	0.2	4.2	1.9
29	17.3	0.0	36.7	19.4	12.2	1.3	2.4	0.8
30	30.8	0.0	42.6	11.8	2.1	2.6	1.5	0.4

Note: Explanation of abbreviations associated with each variable. (All values are recorded as % cover.)

JUOS - % *Juniperus osteosperma*
PIED - % *Pinus edulis*
TLIVG - % Total living cover
UNSTY - % Understory vegetation
PGRAS - % Perennial grasses
AGRAS - % Annual grasses
SHRUB - % Shrubs
PFORB - % Perennial forbs

STUDY SITE #	AFORB	TRECV	TRAGE	SPCRC	DECCV	INCCV	DEFRQ	INFRQ
1	0.0	47.5	102.0	15.0	80.2	6.3	39.7	11.0
2	0.1	43.0	101.0	17.0	14.0	80.7	18.4	26.5
3	0.0	62.3	60.0	13.0	55.4	44.6	21.4	19.6
4	0.1	50.5	104.0	20.0	24.9	57.0	23.2	26.1
5	0.0	17.0	82.0	16.0	69.1	3.1	42.2	6.7
6	0.0	42.5	88.0	14.0	52.6	3.1	28.4	4.2
7	0.0	51.5	90.0	11.0	89.4	8.6	27.3	7.6
8	0.0	47.0	108.0	15.0	48.7	5.7	24.4	5.1
9	0.2	49.3	98.0	15.0	97.2	0.0	28.1	3.1
10	0.0	62.5	103.0	15.0	37.3	29.7	34.8	17.4
11	0.0	35.0	89.0	15.0	57.6	20.5	41.7	9.4
12	0.0	61.0	79.0	10.0	53.4	34.5	16.7	16.7
13	0.0	40.0	111.0	13.0	42.4	36.4	30.7	18.7
14	0.0	33.0	105.0	16.0	57.5	6.2	18.1	1.2
15	0.0	40.0	62.0	13.0	57.3	41.3	22.2	18.5
16	0.1	52.0	68.0	10.0	82.7	14.5	4.2	19.6
17	0.1	36.0	98.0	17.0	63.4	15.5	40.4	12.8
18	0.0	53.0	81.0	13.0	79.7	14.1	34.9	14.3
19	0.2	37.6	98.0	15.0	65.0	22.2	22.4	15.8
20	0.0	42.8	53.0	10.0	64.5	44.7	31.3	22.9
21	0.0	32.1	113.0	20.0	50.9	32.1	35.2	15.5
22	0.0	35.8	79.0	14.0	47.6	9.7	29.7	9.9
23	0.0	27.0	93.0	13.0	59.6	30.8	39.7	13.2
24	0.0	35.0	36.0	15.0	64.4	34.2	37.0	32.9
25	0.0	23.8	79.0	18.0	78.4	11.6	47.3	6.8
26	0.0	27.6	86.0	12.0	64.6	32.6	28.9	15.4
27	0.0	25.5	81.0	19.0	27.2	40.8	26.6	12.5
28	0.0	20.8	92.0	19.0	41.8	38.2	29.9	16.9
29	0.0	17.3	94.0	14.0	75.8	8.8	36.2	8.7
30	0.0	35.3	92.0	12.0	58.5	27.1	22.4	13.8

Note: Explanation of abbreviations associated with each variable. (All values are recorded as % cover.)

AFORB - % Annual forb cover
TRECV - % Tree cover
TRAGE - Tree average age (yrs.)
SPCDV - Species richness (species/site)
(Tree species not included in species richness index)

DECCV - Decreaser species cover
INCCV - Increaser species cover
DEFRQ - Decreaser species frequency
INFRQ - Increaser species frequency

STUDY SITE #	TNLIV	ROCK	BRGRD	LITTR	SGRAV	%GRAV	%SAND	%SILT
1	35.7	0.8	22.0	50.0	12.9	11.0	44.0	40.0
2	38.5	13.1	7.7	51.1	17.7	10.0	16.0	32.0
3	55.2	13.7	13.8	41.5	27.7	16.0	40.0	52.0
4	49.3	13.2	31.3	42.6	4.8	5.0	20.0	34.0
5	32.9	0.7	25.1	32.1	7.1	11.0	48.0	40.0
6	49.3	8.7	14.0	31.3	26.6	10.0	58.0	34.0
7	40.8	6.2	15.2	47.8	19.4	15.0	46.0	40.0
8	51.6	9.5	21.5	41.5	20.6	11.0	24.0	36.0
9	42.9	14.7	8.6	49.3	19.6	16.0	52.0	40.0
10	31.7	9.7	15.5	54.2	6.5	6.0	40.0	32.0
11	39.7	0.5	16.0	42.5	23.2	13.0	46.0	46.0
12	56.6	13.9	21.5	34.0	21.2	10.0	32.0	54.0
13	64.5	30.3	21.0	36.0	13.2	12.0	24.0	34.0
14	66.6	22.7	13.3	25.0	30.6	18.0	60.0	32.0
15	66.6	15.8	14.8	30.7	36.0	18.0	36.0	46.0
16	59.0	16.4	12.6	31.3	30.0	20.0	31.0	45.0
17	43.5	10.7	28.6	41.6	4.2	7.0	37.0	31.0
18	59.0	11.9	11.7	34.4	35.4	18.0	44.0	48.0
19	57.4	14.5	15.6	37.1	27.3	15.0	41.0	41.0
20	62.2	16.4	14.9	26.7	30.9	17.0	30.0	52.0
21	57.0	1.1	2.8	43.2	33.1	8.0	33.0	37.0
22	47.1	0.1	6.6	28.4	0.4	1.0	44.0	34.0
23	61.5	12.2	28.3	29.5	21.0	4.0	49.0	25.0
24	48.5	1.2	11.6	33.8	35.7	20.0	48.0	36.0
25	45.0	6.1	27.6	23.6	11.3	12.0	49.0	29.0
26	38.4	0.8	20.8	53.8	16.8	9.0	53.0	23.0
27	68.1	7.0	29.2	24.0	31.9	9.0	25.0	31.0
28	50.6	1.3	37.5	24.7	11.8	2.0	16.0	36.0
29	65.2	8.7	27.1	20.7	29.4	10.0	43.0	35.0
30	57.9	9.3	6.6	30.6	42.0	21.0	42.0	50.0

Note: Explanation of abbreviations associated with each variable. (All values are recorded as % cover.)

TNLIV - % Total nonliving cover
ROCK - % Surface rock cover
BRGRD - % Bare ground cover
LITTR - % Litter cover
SGRAV - % Surface gravel cover
%GRAV - % Soil gravel
%SAND - % Sand
%SILT - % Silt

STUDY SITE #	%CLAY	VALUE	%SLPE	ASPCT	PTAVE	SOILL	ASOLL	SOILV
1	16.0	4.0	7.0	250.0	24.4	1043.0	548.0	10.2
2	52.0	5.0	15.0	210.0	20.0	1110.0	633.0	10.9
3	8.0	4.0	17.0	260.0	20.0	1403.0	529.0	23.9
4	46.0	5.0	24.0	160.0	29.7	673.0	334.0	6.6
5	12.0	5.0	6.0	115.0	23.1	873.0	725.0	11.0
6	8.0	5.0	16.0	250.0	20.0	1503.0	864.0	17.1
7	14.0	4.0	13.0	240.0	21.7	1153.0	559.0	12.8
8	40.0	5.0	12.0	220.0	18.5	637.0	338.0	5.9
9	8.0	4.0	16.0	225.0	16.9	987.0	501.0	10.1
10	28.0	5.0	14.0	210.0	20.0	1130.0	424.0	11.2
11	8.0	4.0	7.0	45.0	30.8	1263.0	822.0	15.8
12	14.0	3.0	12.0	250.0	14.1	1867.0	728.0	25.7
13	42.0	4.0	31.0	150.0	27.2	1013.0	608.0	11.0
14	8.0	5.0	20.0	250.0	27.2	1067.0	715.0	10.1
15	18.0	4.0	10.0	253.0	14.7	1223.0	734.0	20.0
16	24.0	4.0	13.0	240.0	9.9	1483.0	712.0	22.0
17	32.0	5.0	10.0	210.0	28.5	1313.0	841.0	13.4
18	8.0	4.0	13.0	240.0	17.4	1380.0	649.0	18.2
19	18.0	4.0	14.0	230.0	23.4	1357.0	846.0	14.0
20	18.0	4.0	12.0	230.0	14.3	1093.0	626.0	21.5
21	30.0	5.0	11.0	25.0	23.8	1813.0	1233.0	17.2
22	22.0	6.0	5.0	180.0	27.1	1103.0	709.0	14.2
23	26.0	5.0	26.0	90.0	25.5	1290.0	942.0	13.9
24	16.0	5.0	11.0	240.0	22.2	1090.0	709.0	31.2
25	22.0	5.0	18.0	270.0	19.8	1567.0	1194.0	20.5
26	24.0	5.0	8.0	228.0	24.4	1630.0	1180.0	19.0
27	44.0	5.0	17.0	160.0	22.5	1517.0	1130.0	19.1
28	48.0	6.0	16.0	165.0	52.3	1227.0	972.0	13.5
29	22.0	5.0	10.0	260.0	19.6	1643.0	1360.0	17.6
30	8.0	4.0	13.0	110.0	19.1	1203.0	779.0	13.0

Note: Explanation of abbreviations associated with each variable. (All values are recorded as % cover.)

%CLAY - % clay
VALUE - Soil color value
%SLPE - % slope
ASPCT - Slope aspect
PTAVE - Average soil penetration (cm)
SOILL - Total soil loss (m^3/ha)
ASOLL - Adjusted total soil loss (m^3/ha)
SOILV - Soil loss rate (m^3/ha/yr)

STUDY SITE #	ASOLV	RFACT	KFACT	LSFCT	CFACT	EROSN	AEROS
1	5.4	40.0	0.15	1.06	0.09	0.57	-0.43
2	6.2	40.0	0.24	1.40	0.04	0.54	-1.46
3	9.0	40.0	0.19	1.20	0.09	0.82	-0.18
4	3.3	40.0	0.28	1.48	0.06	0.99	-0.01
5	9.1	40.0	0.21	1.25	0.04	0.42	-0.58
6	9.8	40.0	0.19	1.52	0.06	0.69	-0.31
7	6.2	40.0	0.19	1.21	0.04	0.37	-0.63
8	3.1	40.0	0.28	1.34	0.13	1.95	0.95
9	5.1	40.0	0.19	1.38	0.04	0.42	-0.58
10	4.2	40.0	0.28	1.12	0.04	0.50	-0.50
11	10.3	40.0	0.24	1.21	0.04	0.46	-1.54
12	10.0	40.0	0.19	1.15	0.09	0.79	-0.21
13	6.6	40.0	0.28	1.70	0.09	1.71	0.71
14	6.7	40.0	0.19	1.71	0.09	1.17	0.17
15	12.0	40.0	0.19	1.24	0.14	1.32	0.32
16	10.5	40.0	0.19	1.25	0.09	0.89	-0.15
17	8.6	40.0	0.28	1.32	0.04	0.59	-0.41
18	8.6	40.0	0.19	1.21	0.09	0.83	-0.17
19	8.8	40.0	0.19	1.44	0.09	0.98	-0.02
20	12.3	40.0	0.19	1.37	0.09	0.94	-0.06
21	11.7	40.0	0.15	1.43	0.09	0.77	-0.23
22	9.1	40.0	0.17	1.01	0.04	0.27	-0.73
23	10.1	40.0	0.28	1.75	0.09	1.76	0.76
24	20.3	40.0	0.19	1.40	0.04	0.43	-0.57
25	15.6	40.0	0.19	1.80	0.04	0.55	-0.45
26	13.7	40.0	0.24	1.28	0.04	0.49	-1.51
27	14.3	40.0	0.28	1.65	0.09	1.66	0.66
28	10.7	40.0	0.28	1.70	0.09	1.71	0.71
29	14.6	40.0	0.19	1.51	0.09	1.03	0.03
30	8.4	40.0	0.19	1.42	0.09	0.97	-0.03

Note: Explanation of abbreviations associated with each variable. (USLE values are actual coefficients used in the equation.)

ASOLV - Adjusted soil loss rate (m^3/ha/yr)
RFACT - USLE rainfall (R) factor
KFACT - USLE soil erosion (K) factor
LSFCT - USLE slope length/gradient (LS) factor
CFACT - USLE cover (C) factor
EROSN - USLE erosion (A) estimates
AEROS - Accelerated erosion (A - T)

STUDY SITE #	BRTE	CRYP	LEPU	AGSP	SIHY	CRFL	PENS
1	1.0	4.7	0.1	0.0	0.3	0.0	3.3
2	8.3	1.0	0.1	0.0	0.1	0.0	0.3
3	3.2	3.2	0.0	0.0	0.8	0.0	0.0
4	8.8	0.8	0.1	0.7	0.5	0.8	0.5
5	0.9	5.6	3.3	21.0	0.0	0.1	0.1
6	0.8	3.6	10.7	11.7	0.0	0.8	0.0
7	1.3	11.9	0.0	0.3	1.0	0.0	0.0
8	0.4	1.8	4.2	0.2	2.2	0.5	5.1
9	0.0	8.3	0.0	0.0	0.6	0.0	0.0
10	6.2	5.7	0.1	1.0	0.5	0.3	0.1
11	2.7	4.3	2.3	2.2	0.0	0.2	1.0
12	1.1	2.0	0.0	0.0	0.4	0.0	0.7
13	5.3	1.5	0.0	3.5	0.1	2.0	0.1
14	0.0	4.5	2.0	1.1	0.7	0.7	0.0
15	2.9	4.0	0.0	0.1	0.0	0.0	0.2
16	1.4	11.8	0.0	0.0	2.5	0.0	0.0
17	2.7	2.0	1.6	0.0	0.2	2.3	8.6
18	1.8	9.0	0.7	0.0	1.0	0.0	0.1
19	2.4	6.0	0.8	0.6	0.6	0.1	0.0
20	0.5	4.5	0.3	0.0	0.2	0.0	0.0
21	2.2	1.9	0.0	0.0	1.7	0.6	1.6
22	2.3	5.4	4.0	6.1	1.8	0.4	0.0
23	4.8	4.2	0.0	4.2	0.1	1.0	0.4
24	3.3	7.2	0.0	0.0	2.9	0.0	0.0
25	3.4	2.7	0.8	19.9	0.0	0.3	0.2
26	4.7	4.9	0.4	0.7	2.6	0.0	1.0
27	3.7	0.2	1.4	1.8	0.2	0.6	0.2
28	0.2	0.0	3.5	10.7	0.3	0.1	0.0
29	1.3	2.7	2.3	11.6	0.0	0.4	0.2
30	2.6	5.2	1.5	1.3	0.2	0.2	0.0

Note: Explanation of abbreviations associated with each variable. (All values are recorded as % cover.)

BRTE - % *Bromus tectorum* (Cheatgrass)
CRYP - % Cryptogams
LEPU - % *Leptodactylon pungens* (Granite pricklygilia)
AGSP - % *Agropyron spicatum* (Bluebunch wheatgrass)
SIHY - % *Sitanion hystrix* (Bottlebrush squirraltail)
CRFL - % *Cryptantha flava* (Yellow cryptantha)
PENS - % *Penstemon spp.*

STUDY SITE #	ORHY	OPPO	SEMU	POPR	ANTE	GUSA	CHVI
1	0.0	0.0	0.6	0.6	0.0	0.0	0.0
2	0.2	0.2	0.0	0.5	0.0	0.0	0.0
3	0.0	0.0	0.0	0.1	0.0	0.0	0.0
4	1.6	0.5	0.0	0.0	0.0	0.5	0.0
5	0.0	2.0	0.0	0.1	0.0	0.2	5.3
6	0.0	0.0	0.0	0.1	0.8	0.0	0.0
7	0.0	0.2	0.3	0.0	0.1	0.0	0.0
8	0.0	0.1	0.2	0.5	0.4	0.0	0.0
9	0.0	0.0	0.1	0.0	0.0	0.0	0.0
10	0.1	6.5	0.4	0.0	0.0	0.0	0.0
11	0.0	0.4	0.1	0.0	0.0	0.0	0.0
12	0.0	0.2	0.0	0.0	0.0	0.9	0.0
13	1.2	1.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.2	0.7	0.7	0.0	0.0
15	0.0	0.1	0.0	0.2	0.0	0.0	0.0
16	0.0	0.5	0.0	1.0	0.0	0.0	0.0
17	0.4	0.5	2.3	0.5	0.1	0.0	0.0
18	0.0	0.1	0.1	0.0	0.0	0.0	0.0
19	0.2	0.0	0.2	0.0	0.1	0.0	0.0
20	0.2	0.0	0.0	0.0	0.0	1.9	0.0
21	0.0	0.0	0.2	0.1	0.0	0.0	0.0
22	0.5	0.8	0.0	0.5	0.0	0.0	4.5
23	0.4	0.3	0.0	0.0	0.1	0.0	0.0
24	3.7	0.0	0.2	0.0	0.0	4.2	0.0
25	0.1	1.1	0.0	0.0	0.1	0.0	0.0
26	0.0	0.0	0.1	0.0	0.0	0.0	0.0
27	0.3	0.3	0.1	0.0	0.0	0.0	0.6
28	0.2	0.0	0.0	10.5	0.3	0.0	0.2
29	0.2	0.0	0.0	0.4	0.2	0.0	0.0
30	0.0	0.0	0.2	0.6	0.0	0.0	0.0

Note: Explanation of abbreviations associated with each variable. (All values are recorded as % cover.)

ORHY - % *Oryzopsis hymenoides* (Indian ricegrass)
OPPO - % *Opuntia polyacantha* (Plains pricklypear)
SEMU - % *Senecio multilobatus* (Lobeleaf groundsel)
POPR - % *Poa pratensis* (Kentucky bluegrass)
ANTE - % *Antennaria spp.* (Pussytoe)
GUSA - % *Gutierrizia sarothrae* (Broom snakeweed)
CHVI - % *Chrysothamnus viscidiflorus* (Little rabbitbrush)

APPENDIX D

PLANT SPECIES ENCOUNTERED WITHIN THE STUDY SITES

LEGEND

N - Native	I - Introduced	P - Perennial	B - Biannual
A - Annual	T - Tree	S - Shrub	H - Half shrub
F - Forb	G - Grass	GL - Grasslike	4 - Succulent

Achillea millefolium (Common yarrow) PNF

Agropyron cristatum (Crested wheatgrass) PIG

Agropyron intermedium (Intermediate wheatgrass) PIG

Agropyron spicatum (Bluebunch wheatgrass) PNG

Antennaria spp. (Pussytoe) PNF

Aristida fendleriana (Fendler threeawn) PNG

Artemisia spinescens (Bud sagebrush) NS

Artemisia tridentata (Big sagebrush) NS

Aster chilensis (Pacific aster) PNF

Astragalus spp. (Locoweed) PNF

Astragalus utahensis (Utah milkvetch) PNF

Bromus inermis (Smooth brome) PNG

Bromus tectorum (Cheatgrass) AIG

Carex kelloggii (Kellogg sedge) PNGL

Cercocarpus montanus (Birchleaf mountain mahogany) NS

Chrysothamnus viscidiflorus (Little rabbitbrush) NS

Cirsium utahense (Utah thistle) BNF

Cryptantha flava (Yellow cryptantha) PNF

Cryptogams (Mosses and Lichens) PNF

Note: The plants are listed in alphabetical order by their scientific name, common name, lifeform and place of origin.

Cynoglossum officinale (Houndstonque) BIF

Descurainia pinnata (Pinnate tansymustard) ANF

Ephedra viridis (Green Mormontea) PNS

Eriogonum umbellatum (Sulfur eriogonum) NHS

Eurotia lanata (Winterfat) NHS

Gilia aggregata (Skyrocket gilia) PNF

Gutierrizia sarothrae (Broom snakeweed) NHS

Juniperus osteosperma (Utah juniper) NT

Lactuca serriola (Prickly lettuce) BIF

Leptodactylon pungens (Granite pricklygilia) NS

Lupinus sericeus (Silky lupine) PNF

Opuntia polyacantha (Plains pricklypear) NS4S

Oryzopsis hymenoides (Indian ricegrass) PNG

Oxytenia acerosa (Copperweed) NHS

Penstemon spp. (Penstemon) PNF

Petradoria pumila (Grassy rockgoldenrod) PNF

Pinus edulis (Pinyon pine) NT

Poa pratensis (Kentucky bluegrass) PIG

Poa secunda (Sandburg bluegrass) PNG

Purshia tridentata (Antelope bitterbrush) NS

Quercus gambelii (Gambel oak) NT

Senecio multilobatus (Lobeleaf groundsel) PNF

Sitanion hystrix (Bottlebrush squirreltail) PNG

Sphaeralcea coccinea (Scarlet globemallow) PNF

Sporobolus cryptandrus (Sand dropseed) PNG

Stipa comata (Needleandthread) PNG

Verbascum thapsus (Flannel mullein) BIF

Viguiera multiflora (Showy goldeneye) PNF

APPENDIX E

PLANT SPECIES LISTED IN DESCENDING ORDER ACCORDING TO THEIR PRESENCE X FREQUENCY INDEX VALUES

LEGEND

N - Native	I - Introduced	P - Perennial	B - Biannual
A - Annual	T - Tree	S - Shrub	H - Half shrub
F - Forb	G - Grass	GL - Grasslike	4 - Succulent

	P X F INDEX
Juniperus osteosperma (Utah juniper) NT	9512
Bromus tectorum (Cheatgrass) AIG	3142
Cryptogams (Mosses and Lichens) PNF	2890
Leptodactylon pungens (Granite pricklygilia) NS	1934
Agropyron spicatum (Bluebunch wheatgrass) PNG	1633
Sitanion hystrix (Bottlebrush squirreltail) PNG	1160
Cryptantha flava (Yellow cryptantha) PNF	977
Penstemon spp. (Penstemon) PNF	727
Oryzopsis hymenoides (Indian ricegrass) PNG	725
Opuntia polyacantha (Plains pricklypear) NS4S	603
Senecio multilobatus (Lobeleaf groundsel) PNF	533
Poa pratensis (Kentucky bluegrass) PIG	498
Antennaria spp. (Pussytoe) PNF	424
Pinus edulis (Pinyon pine) NT	342
Gutierrizia sarothrae (Broom snakeweed) NHS	273
Chrysothamnus viscidiflorus (Little rabbitbrush) NS	264
Quercus gambelii (Gambel oak) NT	196
Cirsium utahense (Utah thistle) BNF	62
Poa secunda (Sandburg bluegrass) PNG	49
Aster chilensis (Pacific aster) PNF	46

Eriogonum umumbellatum (Sulfur eriogonum) NHS	31
Verbascum thapsus (Flannel mullein) BIF	30
Carex kelloggii (Kellogg sedge) PNGL	26
Purshia tridentata (Antelope bitterbrush) NS	23
Stipa comata (Needleandthread) PNG	20
Petradoria pumila (Rock goldenrod) PNF	17
Agropyron cristatum (Crested wheatgrass) PIG	17
Viguiera multiflora (Showy goldeneye) PNF	16
Artemisia tridentata (Big sagebrush) NS	12
Cynoglossum officinale (Houndstonque) BIF	12
Sphaeralcea coccinea (Scarlet globemallow) PNF	5
Astragalus utahensis (Utah milkvetch) PNF	5
Astragalus spp. (Locoweed) PNF	4
Eurotia lanata (Winterfat) NHS	2
Agropyron intermedium (Intermediate wheatgrass) PIG	2
Lupinus sericeus (Silky lupine) PNF	1
Oxytenia acerosa (Copperweed) NHS	1
Achillea millefolium (Common yarrow) PNF	1
Descurainia pinnata (Pinnate tansy mustard) ANF	1
Lactuca serriola (Prickly lettuce) BIF	1
Artemisia spinescens (Bud sagebrush) NS	0.5
Bromus inermis (Smooth brome) PNG	0.5
Sporobolus cryptandrus (Sand dropseed) PNG	0.5
Ephedra viridis (Green Mormontea) PNS	0.5
Gilia aggregata (Skyrocket gilia) PNF	0.5
Cercocarpus montanus (Birchleaf mountain mahogany) NS	0.5
Aristida fendleriana (Fendler threeawn) PNG	0.5

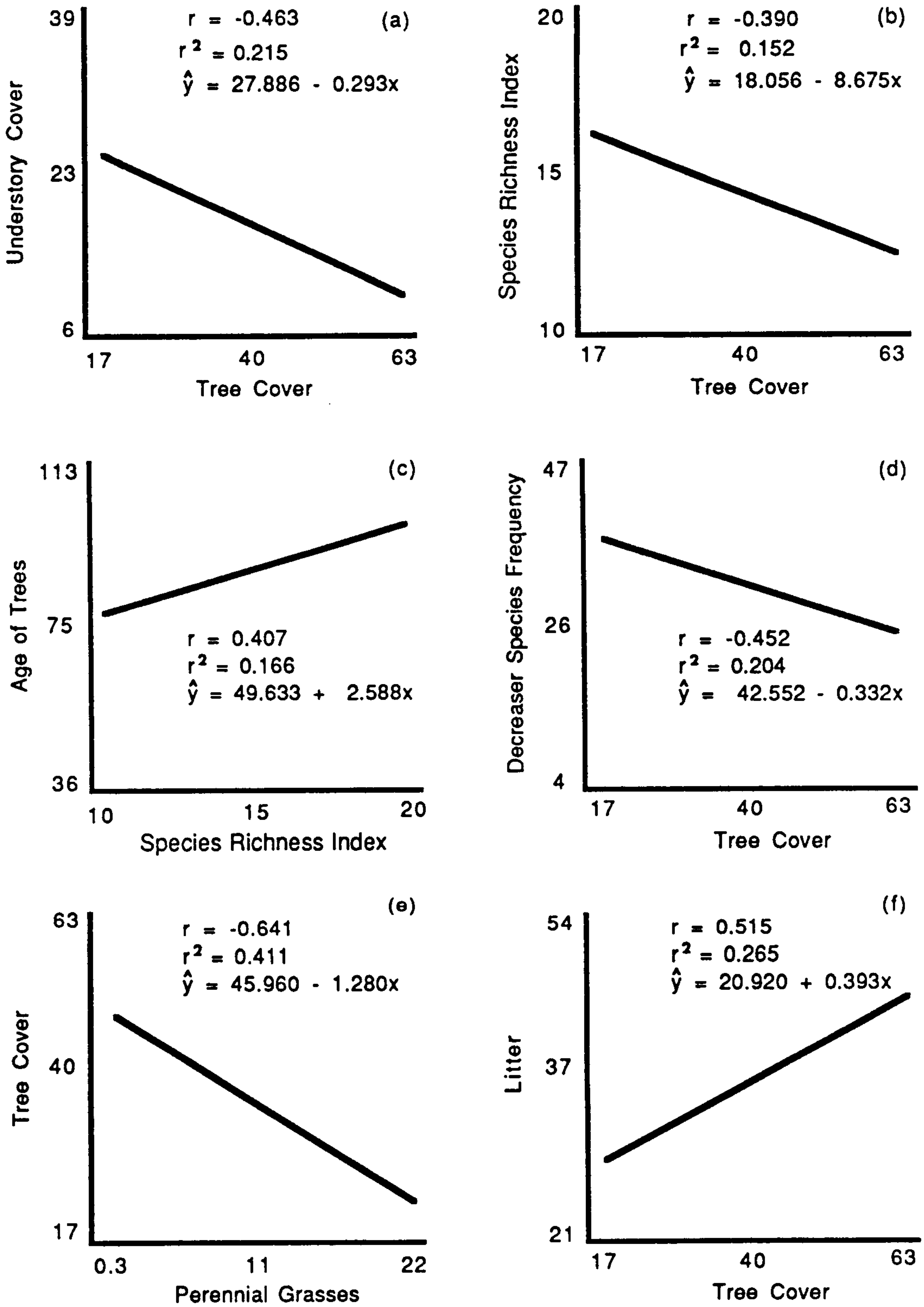
APPENDIX F

SIXTEEN MOST PREVALENT PLANT SPECIES RANKED ACCORDING TO THEIR CALCULATED PRESENCE X FREQUENCY INDEX

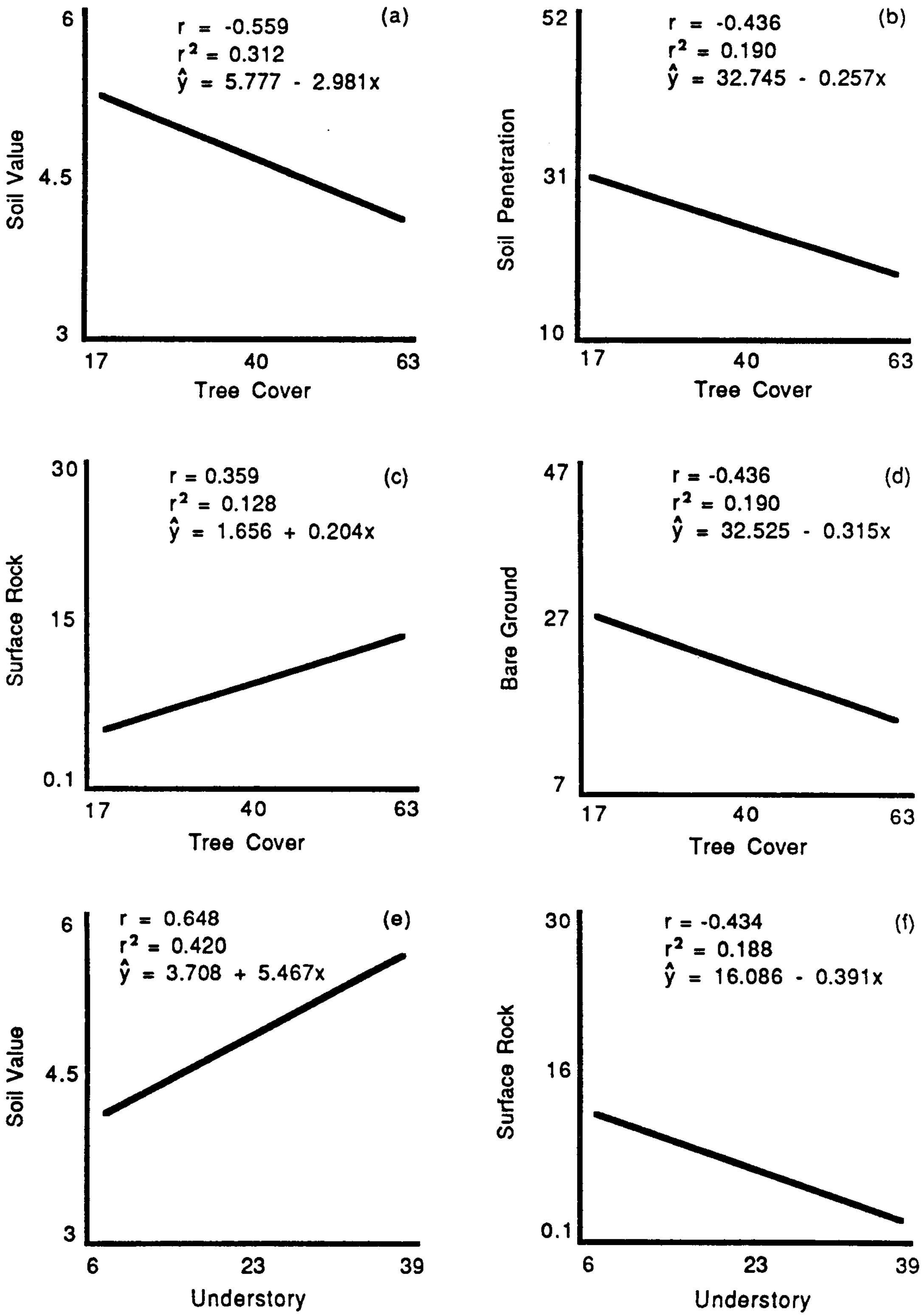
	P X F INDEX
1. *Juniperus osteosperma* (Utah juniper) NT	9512
2. *Bromus tectorum* (Cheatgrass) AIG	3142
3. *Cryptogams* (Mosses and Lichens) PNF	2890
4. *Leptodactylon pungens* (Granite pricklygilia) NS	1934
5. *Agropyron spicatum* (Bluebunch wheatgrass) PNG	1633
6. *Sitanion hystrix* (Bottlebrush squirreltail) PNG	1160
7. *Cryptantha flava* (Yellow cryptantha) PNF	977
8. *Penstemon spp.* (Penstemon) PNF	727
9. *Oryzopsis hymenoides* (Indian ricegrass) PNG	725
10. *Opuntia polyacantha* (Plains pricklypear) NS4S	603
11. *Senecio multilobatus* (Lobeleaf groundsel) PNF	533
12. *Poa pratensis* (Kentucky bluegrass) PIG	498
13. *Antennaria spp.* (Pussytoe) PNF	424
14. *Pinus edulis* (Pinyon pine) NT	342
15. *Gutierrizia sarothrae* (Broom snakeweed) NHS	273
16. *Chrysothamnus viscidiflorus* (Little rabbitbrush) NS	264

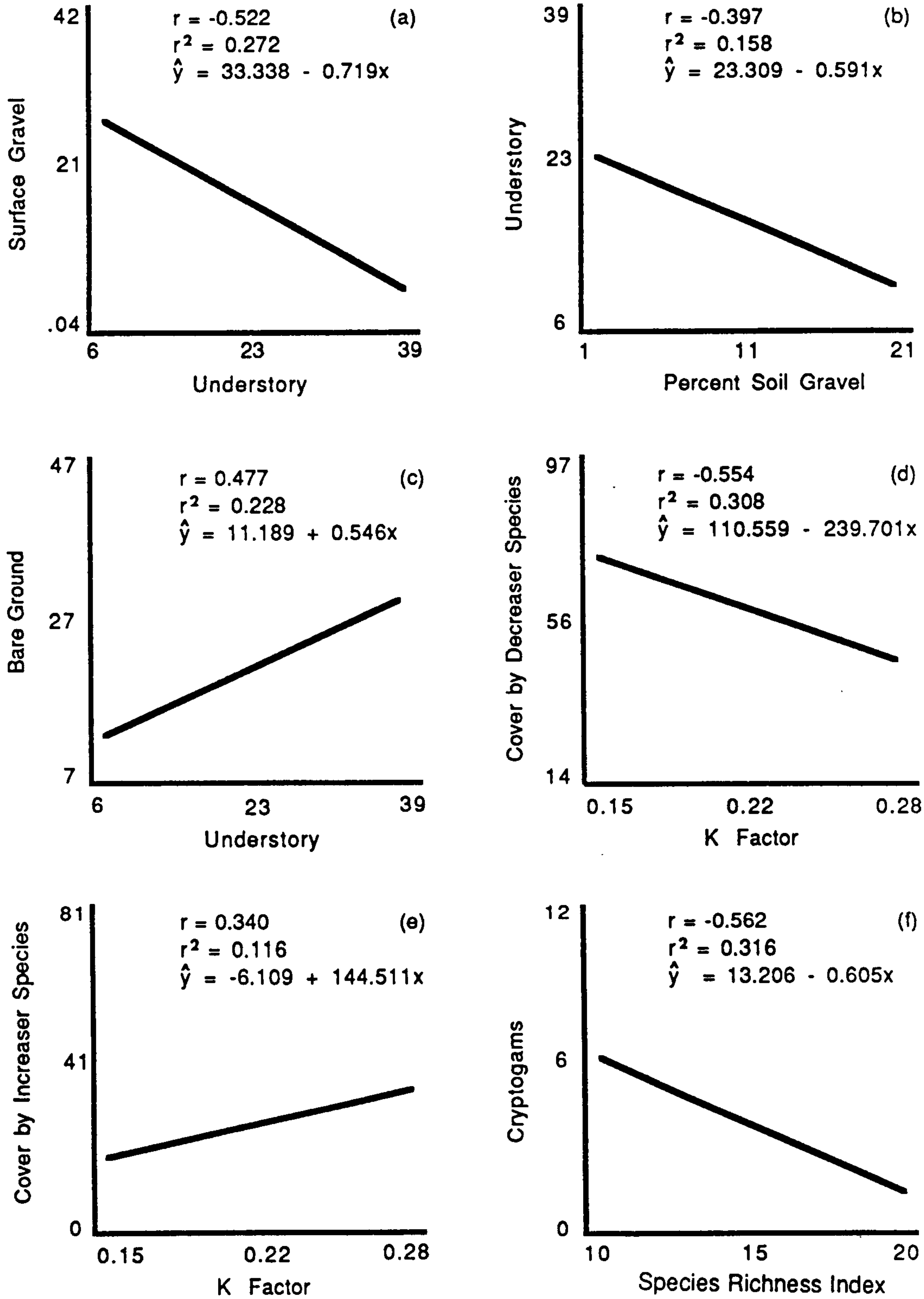
APPENDIX G

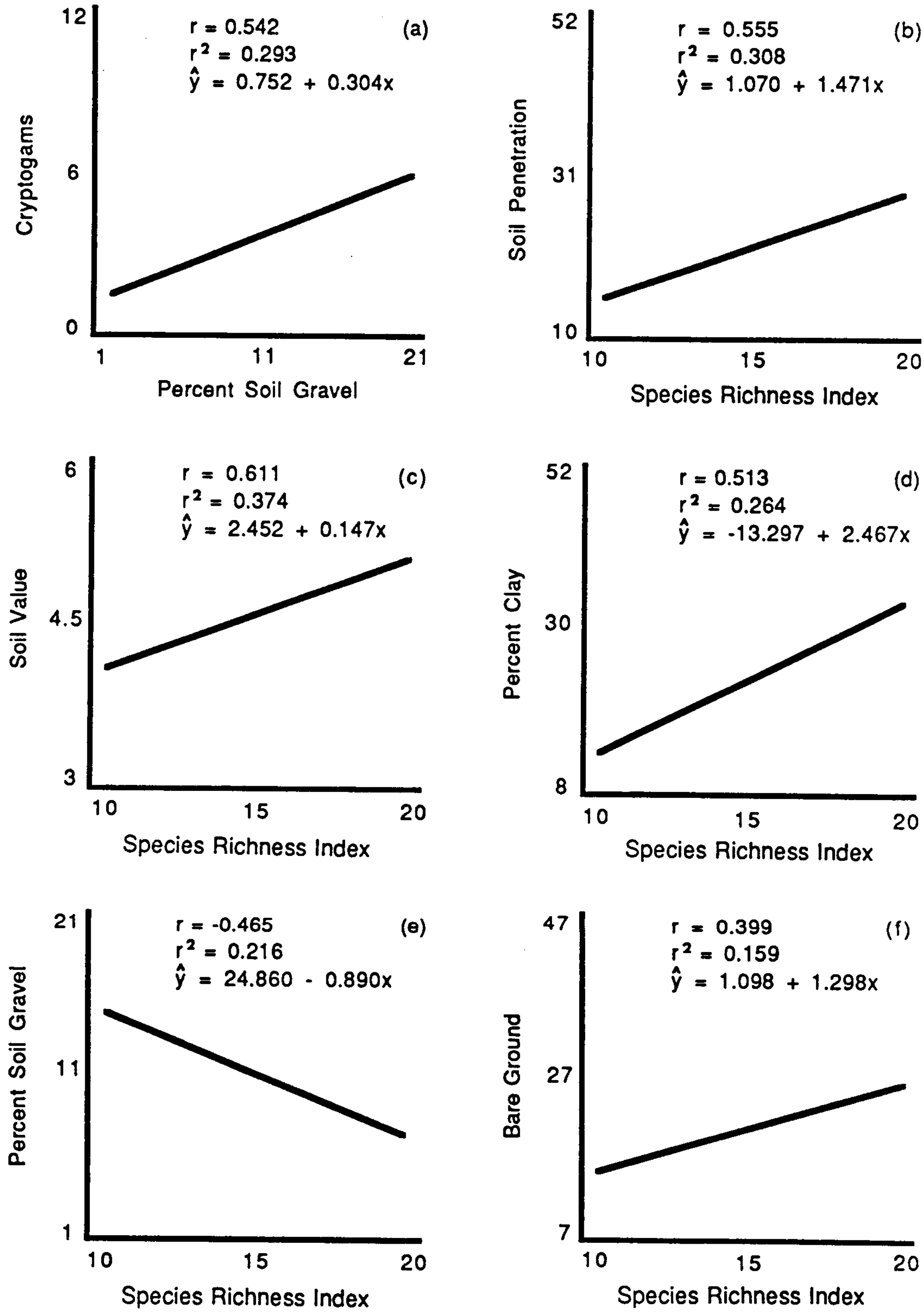
X-Y SCATTER PLOTS GENERATED USING
SIMPLE REGRESSION ANALYSIS



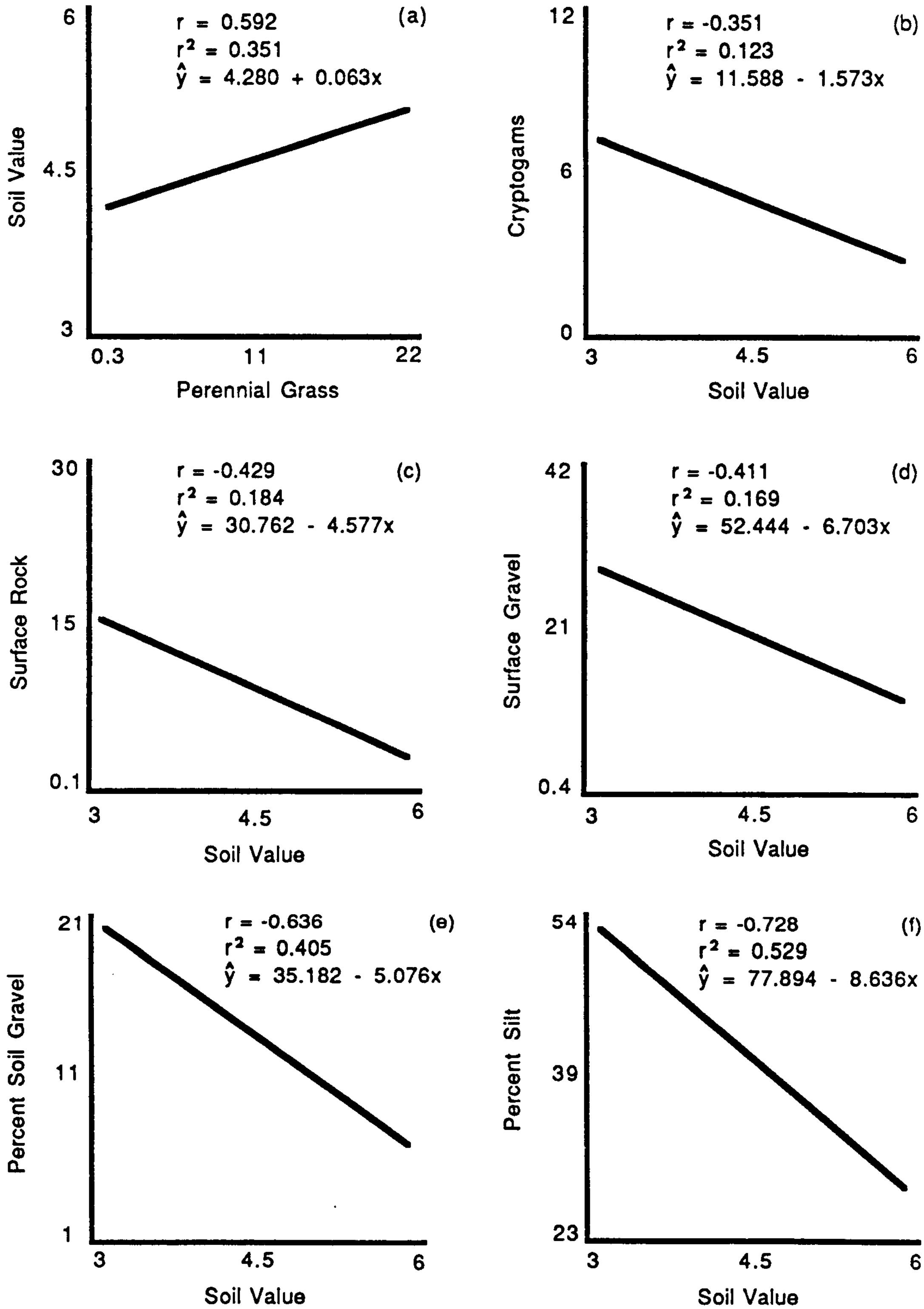
r = -0.463
r² = 0.215
ŷ = 27.886 - 0.293x
(a)
39
23
6
Understory Cover
17
40
63
Tree Cover
r = -0.390
r² = 0.152
ŷ = 18.056 - 8.675x
(b)
20
15
10
Species Richness Index
17
40
63
Tree Cover
(c)
113
75
36
Age of Trees
r = 0.407
r² = 0.166
ŷ = 49.633 + 2.588x
10
15
20
Species Richness Index
(d)
47
26
4
Decreaser Species Frequency
r = -0.452
r² = 0.204
ŷ = 42.552 - 0.332x
17
40
63
Tree Cover
(e)
63
40
17
Tree Cover
r = -0.641
r² = 0.411
ŷ = 45.960 - 1.280x
0.3
11
22
Perennial Grasses
(f)
54
37
21
Litter
r = 0.515
r² = 0.265
ŷ = 20.920 + 0.393x
17
40
63
Tree Cover


(a)
r = -0.559
r² = 0.312
ŷ = 5.777 - 2.981x
Soil Value
6
4.5
3
17
40
63
Tree Cover
(b)
r = -0.436
r² = 0.190
ŷ = 32.745 - 0.257x
Soil Penetration
52
31
10
17
40
63
Tree Cover
(c)
r = 0.359
r² = 0.128
ŷ = 1.656 + 0.204x
Surface Rock
30
15
0.1
17
40
63
Tree Cover
(d)
r = -0.436
r² = 0.190
ŷ = 32.525 - 0.315x
Bare Ground
47
27
7
17
40
63
Tree Cover
(e)
r = 0.648
r² = 0.420
ŷ = 3.708 + 5.467x
Soil Value
6
4.5
3
6
23
39
Understory
(f)
r = -0.434
r² = 0.188
ŷ = 16.086 - 0.391x
Surface Rock
30
16
0.1
6
23
39
Understory

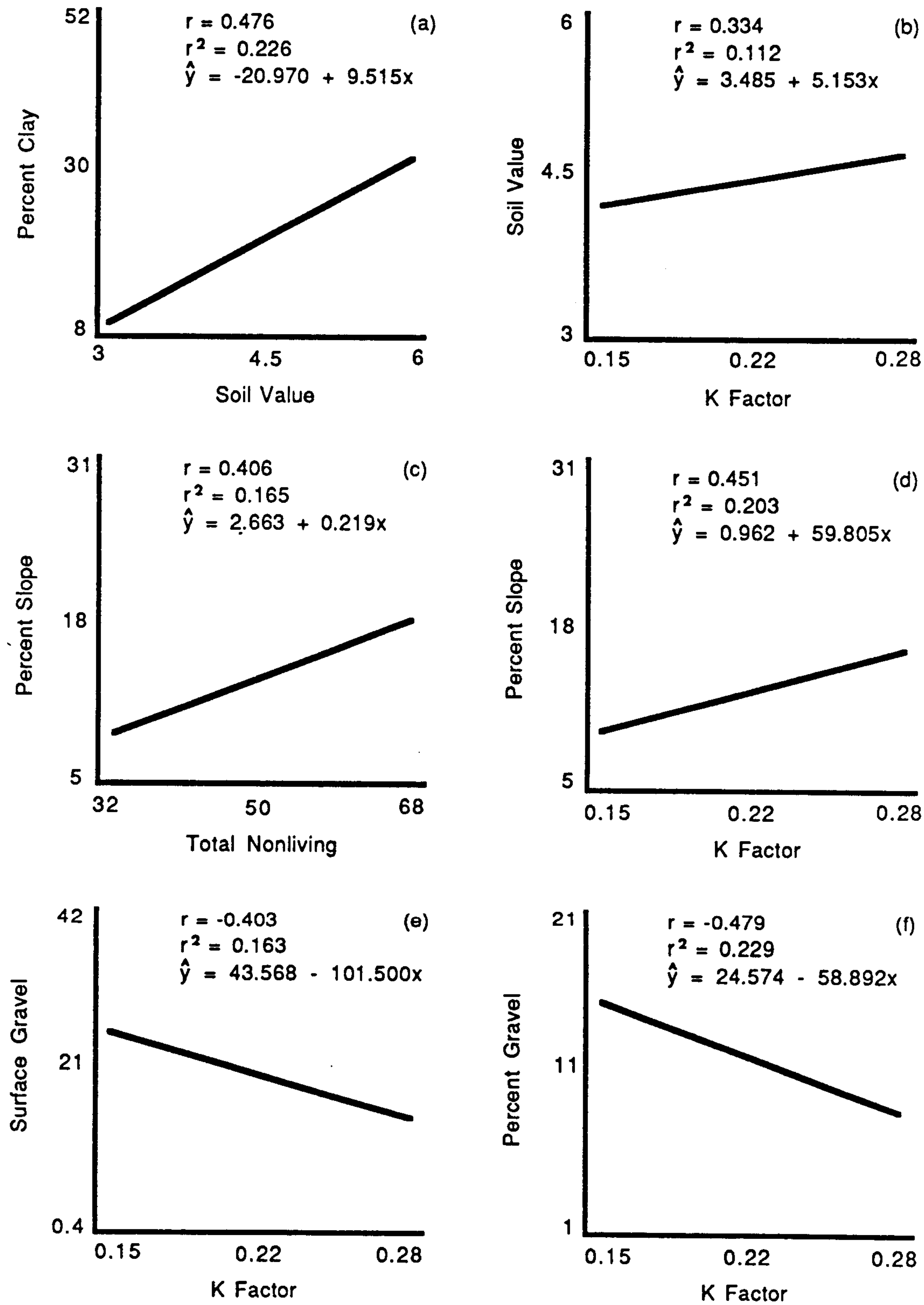

r = -0.522
(a)
r² = 0.272
ŷ = 33.338 - 0.719x
Surface Gravel
42
21
.04
6
23
39
Understory
r = -0.397
(b)
r² = 0.158
ŷ = 23.309 - 0.591x
Understory
39
23
6
1
11
21
Percent Soil Gravel
r = 0.477
(c)
r² = 0.228
ŷ = 11.189 + 0.546x
Bare Ground
47
27
7
6
23
39
Understory
r = -0.554
(d)
r² = 0.308
ŷ = 110.559 - 239.701x
Cover by Decreaser Species
97
56
14
0.15
0.22
0.28
K Factor
r = 0.340
(e)
r² = 0.116
ŷ = -6.109 + 144.511x
Cover by Increaser Species
81
41
0
0.15
0.22
0.28
K Factor
r = -0.562
(f)
r² = 0.316
ŷ = 13.206 - 0.605x
Cryptogams
12
6
0
10
15
20
Species Richness Index



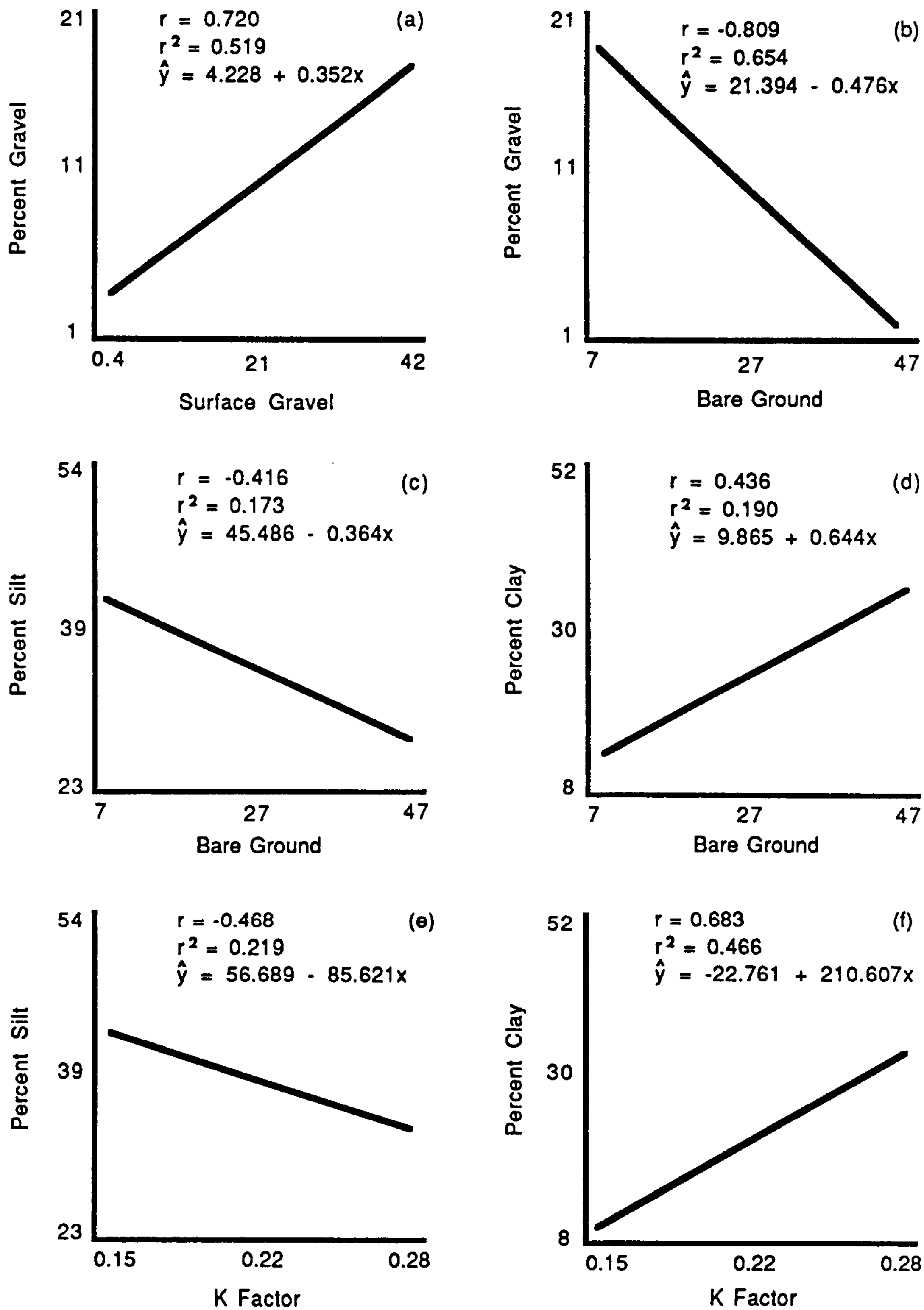
(a)
r = 0.542
r² = 0.293
ŷ = 0.752 + 0.304x
Cryptogams
12
6
0
1
11
21
Percent Soil Gravel
(b)
r = 0.555
r² = 0.308
ŷ = 1.070 + 1.471x
Soil Penetration
52
31
10
10
15
20
Species Richness Index
(c)
r = 0.611
r² = 0.374
ŷ = 2.452 + 0.147x
Soil Value
6
4.5
3
10
15
20
Species Richness Index
(d)
r = 0.513
r² = 0.264
ŷ = -13.297 + 2.467x
Percent Clay
52
30
8
10
15
20
Species Richness Index
(e)
r = -0.465
r² = 0.216
ŷ = 24.860 - 0.890x
Percent Soil Gravel
21
11
1
10
15
20
Species Richness Index
(f)
r = 0.399
r² = 0.159
ŷ = 1.098 + 1.298x
Bare Ground
47
27
7
10
15
20
Species Richness Index



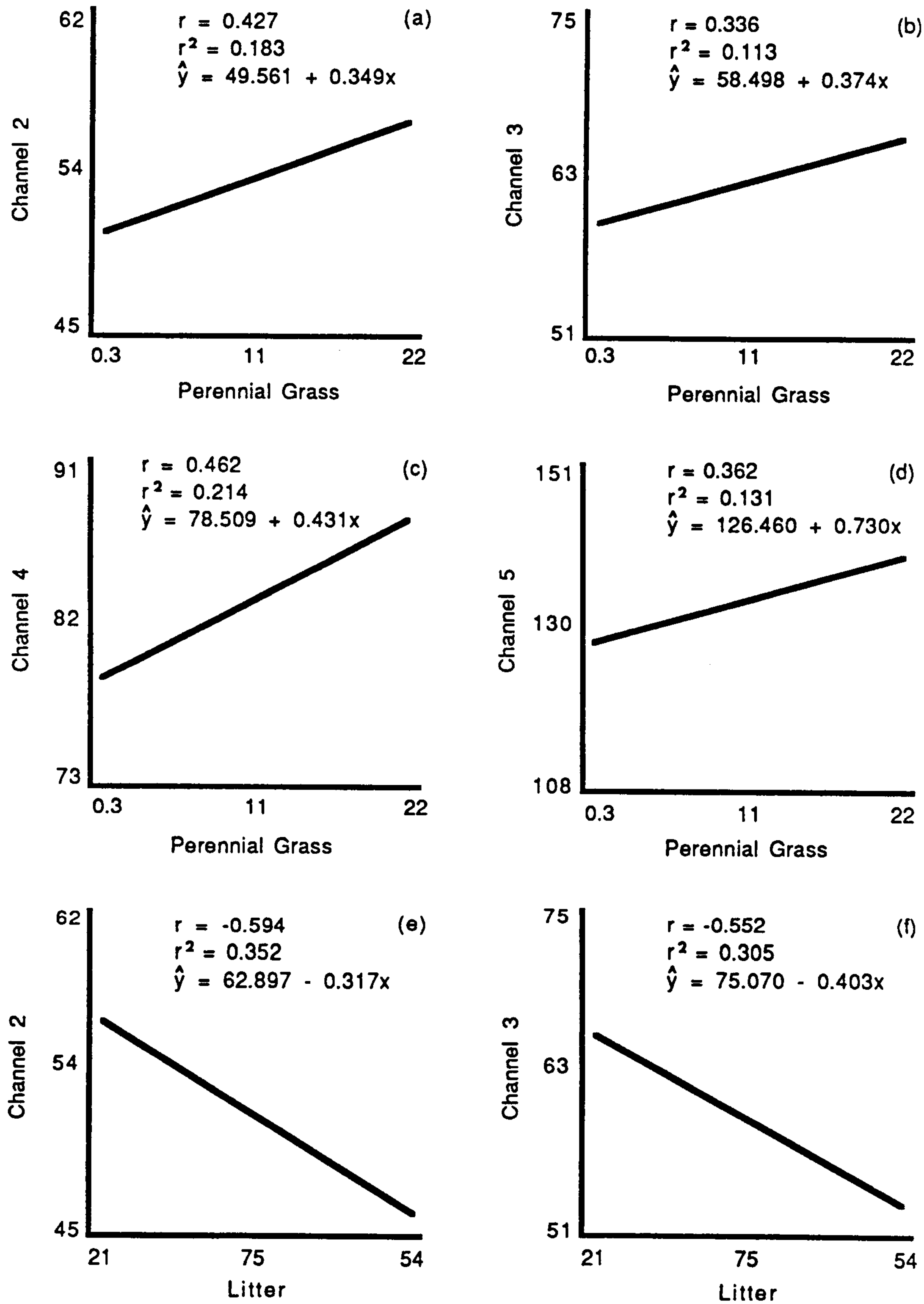
r = 0.592
r² = 0.351
ŷ = 4.280 + 0.063x
(a)
6
4.5
3
Soil Value
0.3
11
22
Perennial Grass
r = -0.351
r² = 0.123
ŷ = 11.588 - 1.573x
(b)
12
6
0
Cryptogams
3
4.5
6
Soil Value
r = -0.429
r² = 0.184
ŷ = 30.762 - 4.577x
(c)
30
15
0.1
Surface Rock
3
4.5
6
Soil Value
r = -0.411
r² = 0.169
ŷ = 52.444 - 6.703x
(d)
42
21
0.4
Surface Gravel
3
4.5
6
Soil Value
r = -0.636
r² = 0.405
ŷ = 35.182 - 5.076x
(e)
21
11
1
Percent Soil Gravel
3
4.5
6
Soil Value
r = -0.728
r² = 0.529
ŷ = 77.894 - 8.636x
(f)
54
39
23
Percent Silt
3
4.5
6
Soil Value

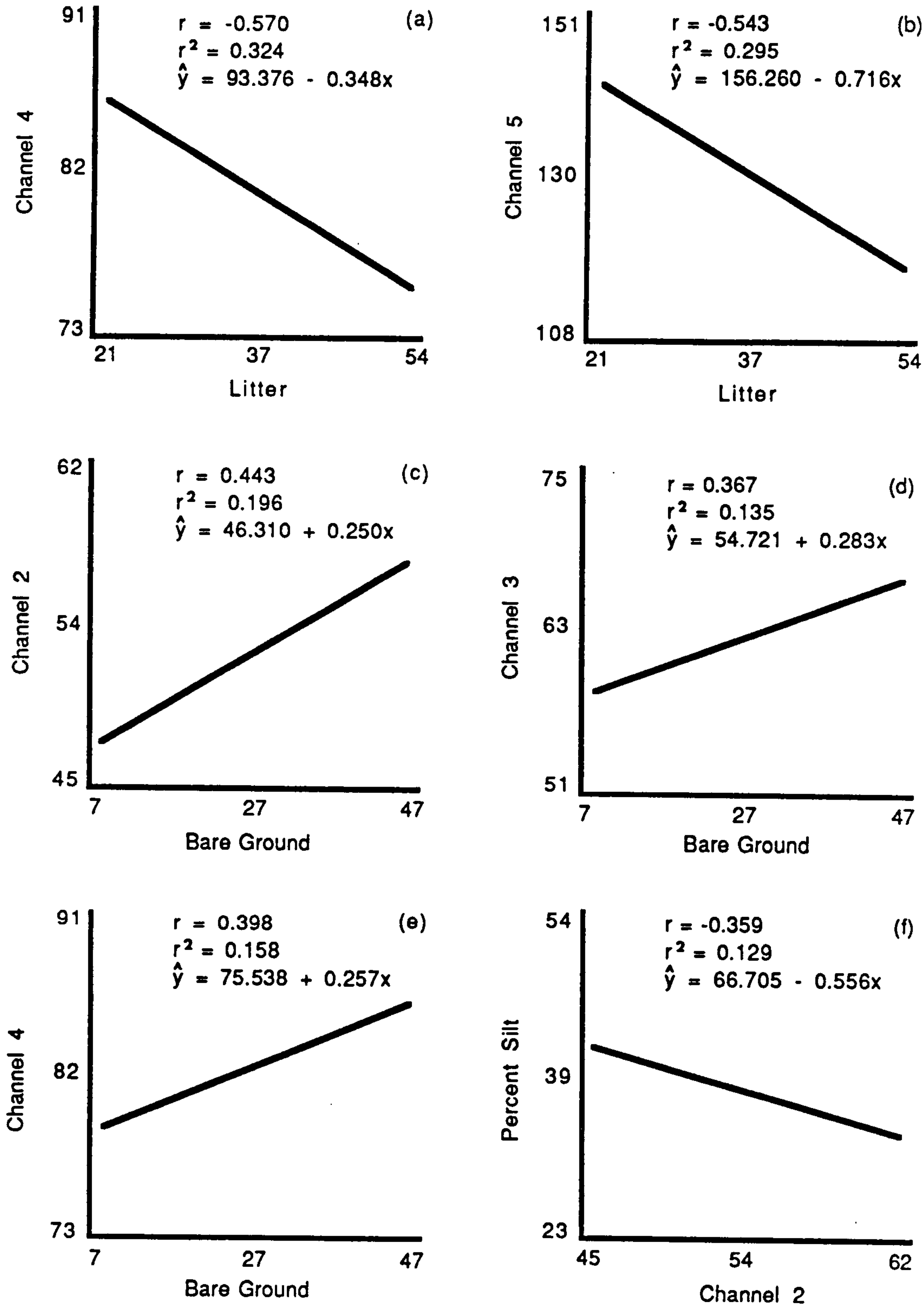


r = 0.476
r² = 0.226
ŷ = -20.970 + 9.515x
(a)
Percent Clay
52
30
8
3
4.5
6
Soil Value
r = 0.334
r² = 0.112
ŷ = 3.485 + 5.153x
(b)
Soil Value
6
4.5
3
0.15
0.22
0.28
K Factor
r = 0.406
r² = 0.165
ŷ = 2.663 + 0.219x
(c)
Percent Slope
31
18
5
32
50
68
Total Nonliving
r = 0.451
r² = 0.203
ŷ = 0.962 + 59.805x
(d)
Percent Slope
31
18
5
0.15
0.22
0.28
K Factor
r = -0.403
r² = 0.163
ŷ = 43.568 - 101.500x
(e)
Surface Gravel
42
21
0.4
0.15
0.22
0.28
K Factor
r = -0.479
r² = 0.229
ŷ = 24.574 - 58.892x
(f)
Percent Gravel
21
11
1
0.15
0.22
0.28
K Factor



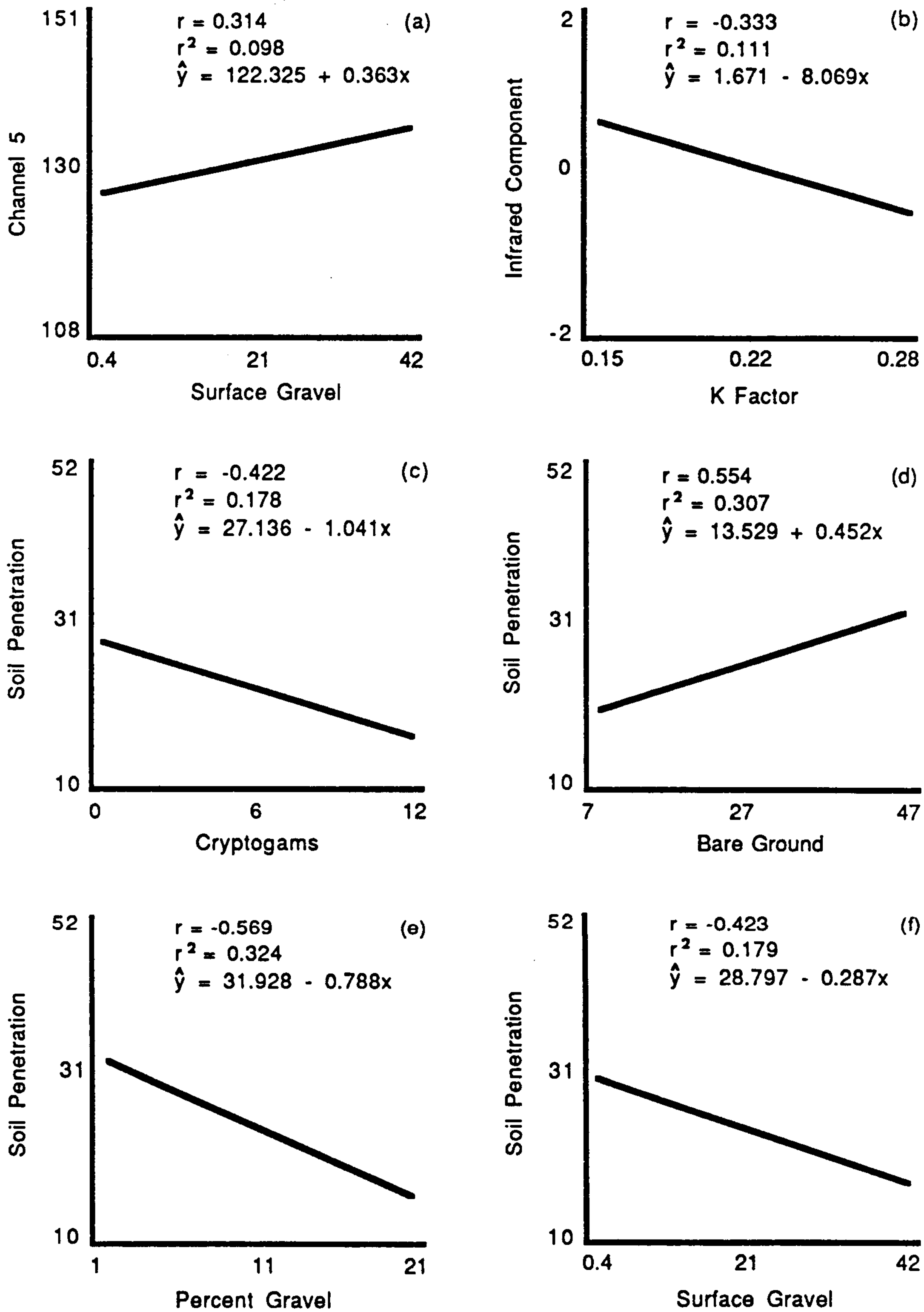
r = 0.720
r² = 0.519
ŷ = 4.228 + 0.352x
(a)
Percent Gravel
21
11
1
0.4
21
42
Surface Gravel
r = -0.809
r² = 0.654
ŷ = 21.394 - 0.476x
(b)
Percent Gravel
21
11
1
7
27
47
Bare Ground
r = -0.416
r² = 0.173
ŷ = 45.486 - 0.364x
(c)
Percent Silt
54
39
23
7
27
47
Bare Ground
r = 0.436
r² = 0.190
ŷ = 9.865 + 0.644x
(d)
Percent Clay
52
30
8
7
27
47
Bare Ground
r = -0.468
r² = 0.219
ŷ = 56.689 - 85.621x
(e)
Percent Silt
54
39
23
0.15
0.22
0.28
K Factor
r = 0.683
r² = 0.466
ŷ = -22.761 + 210.607x
(f)
Percent Clay
52
30
8
0.15
0.22
0.28
K Factor


(a)
r = 0.427
r² = 0.183
ŷ = 49.561 + 0.349x
Channel 2
62
54
45
0.3
11
22
Perennial Grass
(b)
r = 0.336
r² = 0.113
ŷ = 58.498 + 0.374x
Channel 3
75
63
51
0.3
11
22
Perennial Grass
(c)
r = 0.462
r² = 0.214
ŷ = 78.509 + 0.431x
Channel 4
91
82
73
0.3
11
22
Perennial Grass
(d)
r = 0.362
r² = 0.131
ŷ = 126.460 + 0.730x
Channel 5
151
130
108
0.3
11
22
Perennial Grass
(e)
r = -0.594
r² = 0.352
ŷ = 62.897 - 0.317x
Channel 2
62
54
45
21
75
54
Litter
(f)
r = -0.552
r² = 0.305
ŷ = 75.070 - 0.403x
Channel 3
75
63
51
21
75
54
Litter

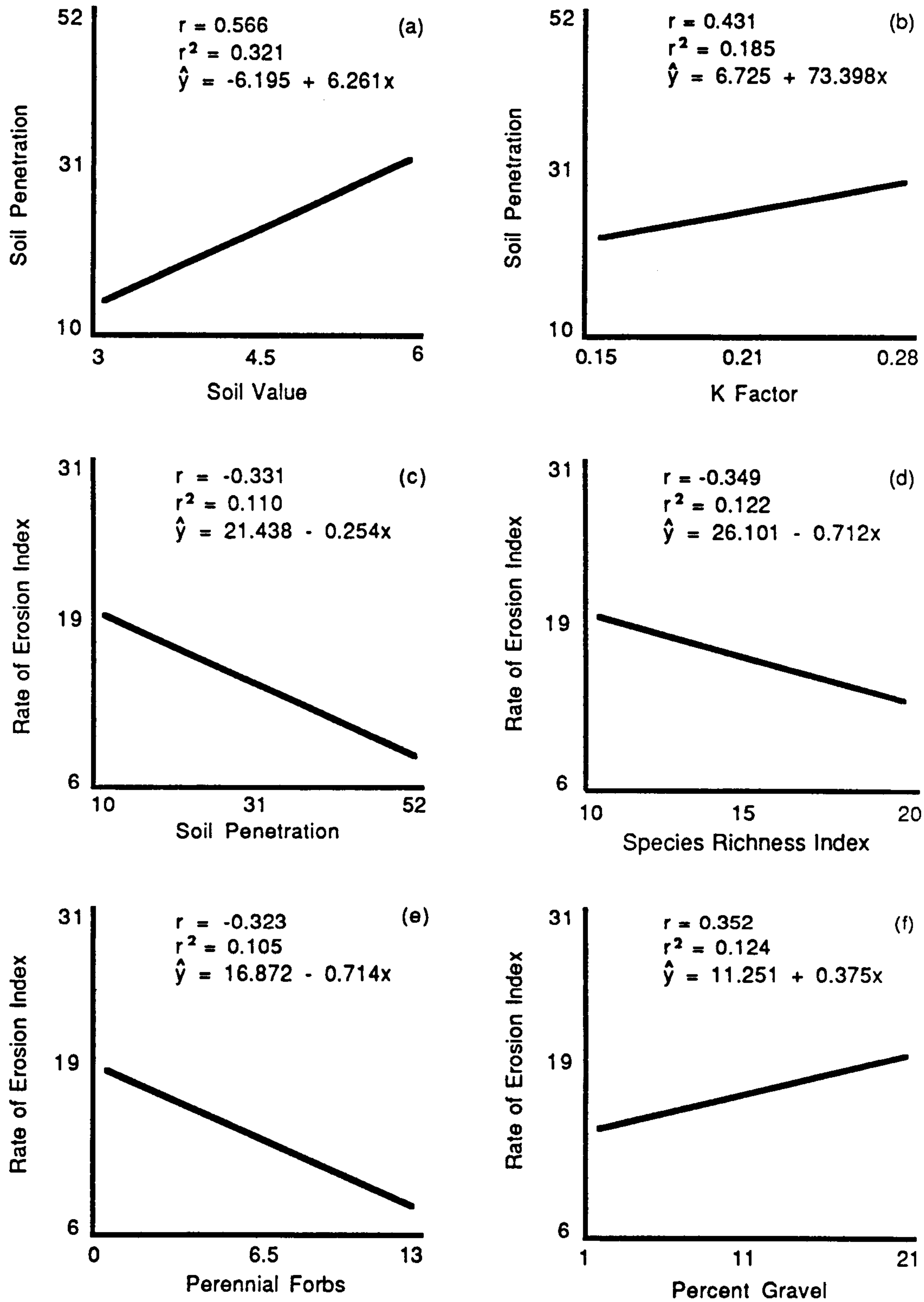


r = -0.570
r² = 0.324
ŷ = 93.376 - 0.348x
(a)
Channel 4
91
82
73
21
37
54
Litter
r = -0.543
r² = 0.295
ŷ = 156.260 - 0.716x
(b)
Channel 5
151
130
108
21
37
54
Litter
r = 0.443
r² = 0.196
ŷ = 46.310 + 0.250x
(c)
Channel 2
62
54
45
7
27
47
Bare Ground
r = 0.367
r² = 0.135
ŷ = 54.721 + 0.283x
(d)
Channel 3
75
63
51
7
27
47
Bare Ground
r = 0.398
r² = 0.158
ŷ = 75.538 + 0.257x
(e)
Channel 4
91
82
73
7
27
47
Bare Ground
r = -0.359
r² = 0.129
ŷ = 66.705 - 0.556x
(f)
Percent Silt
54
39
23
45
54
62
Channel 2

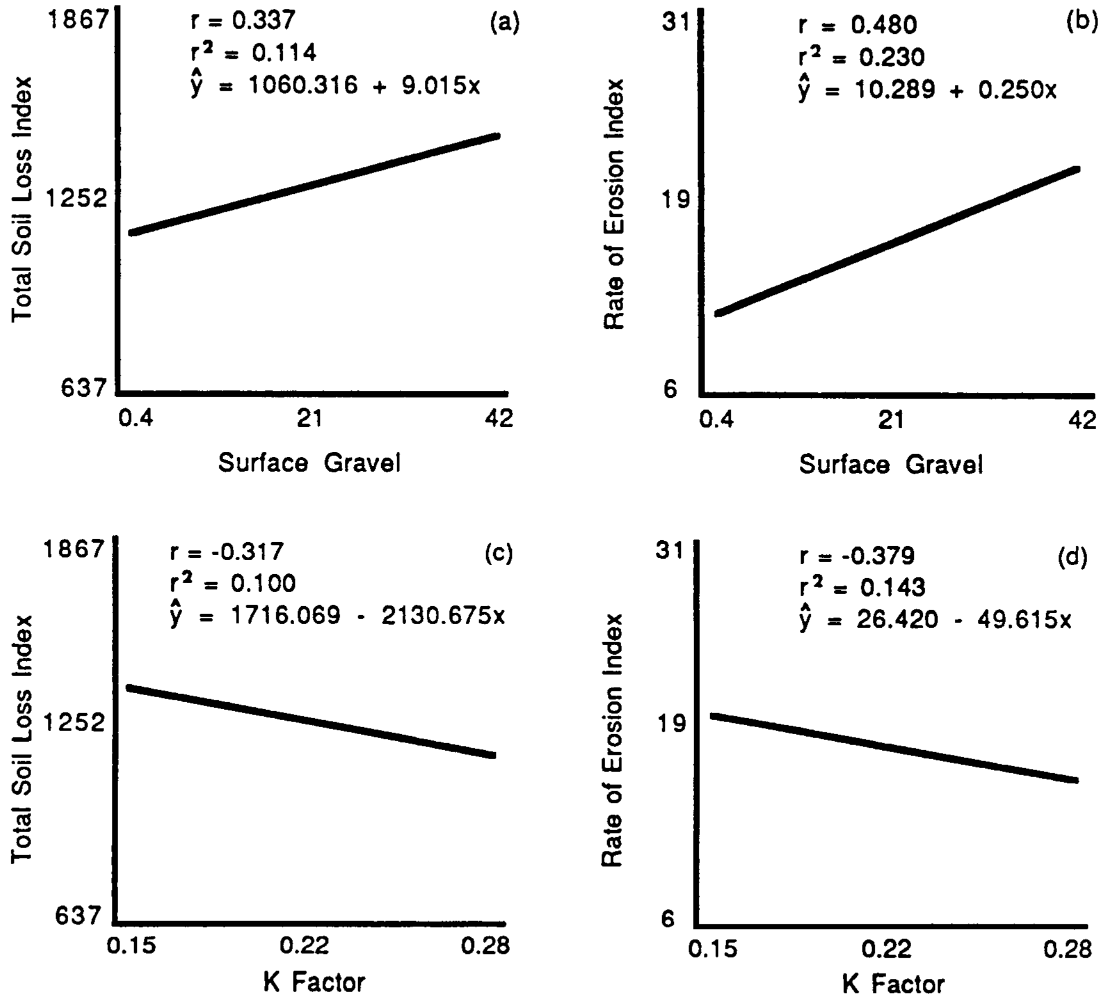
C-3



r = 0.314
r² = 0.098
ŷ = 122.325 + 0.363x
(a)
151
130
108
Channel 5
0.4
21
42
Surface Gravel
r = -0.333
r² = 0.111
ŷ = 1.671 - 8.069x
(b)
2
0
-2
Infrared Component
0.15
0.22
0.28
K Factor
r = -0.422
r² = 0.178
ŷ = 27.136 - 1.041x
(c)
52
31
10
Soil Penetration
0
6
12
Cryptogams
r = 0.554
r² = 0.307
ŷ = 13.529 + 0.452x
(d)
52
31
10
Soil Penetration
7
27
47
Bare Ground
r = -0.569
r² = 0.324
ŷ = 31.928 - 0.788x
(e)
52
31
10
Soil Penetration
1
11
21
Percent Gravel
r = -0.423
r² = 0.179
ŷ = 28.797 - 0.287x
(f)
52
31
10
Soil Penetration
0.4
21
42
Surface Gravel



52
31
10
Soil Penetration
r = 0.566
r² = 0.321
ŷ = -6.195 + 6.261x
(a)
3
4.5
6
Soil Value
52
31
10
Soil Penetration
r = 0.431
r² = 0.185
ŷ = 6.725 + 73.398x
(b)
0.15
0.21
0.28
K Factor
31
19
6
Rate of Erosion Index
r = -0.331
r² = 0.110
ŷ = 21.438 - 0.254x
(c)
10
31
52
Soil Penetration
31
19
6
Rate of Erosion Index
r = -0.349
r² = 0.122
ŷ = 26.101 - 0.712x
(d)
10
15
20
Species Richness Index
31
19
6
Rate of Erosion Index
r = -0.323
r² = 0.105
ŷ = 16.872 - 0.714x
(e)
0
6.5
13
Perennial Forbs
31
19
6
Rate of Erosion Index
r = 0.352
r² = 0.124
ŷ = 11.251 + 0.375x
(f)
1
11
21
Percent Gravel



r = 0.337
r² = 0.114
ŷ = 1060.316 + 9.015x
(a)
Total Soil Loss Index
1867
1252
637
0.4
21
42
Surface Gravel
r = 0.480
r² = 0.230
ŷ = 10.289 + 0.250x
(b)
Rate of Erosion Index
31
19
6
0.4
21
42
Surface Gravel
r = -0.317
r² = 0.100
ŷ = 1716.069 - 2130.675x
(c)
Total Soil Loss Index
1867
1252
637
0.15
0.22
0.28
K Factor
r = -0.379
r² = 0.143
ŷ = 26.420 - 49.615x
(d)
Rate of Erosion Index
31
19
6
0.15
0.22
0.28
K Factor

APPENDIX H

INDEPENDENT AND DEPENDENT VARIABLES USED IN STEPWISE MULTIPLE REGRESSION ANALYSIS

FACTORS:*	MEAN	STANDARD DEVIATION
Channel 2	51.30	5.20
Channel 3	60.40	7.10
Channel 4	80.70	5.90
Channel 5	130.20	12.70
PCA 1 of 1 (Single component)**	-0.16	1.00
PCA 1 of 2 (Visible component)	-0.15	1.00
PCA 2 of 2 (Infrared component)	-0.08	1.10
% Juniper	34.30	11.40
% Pinyon pine	4.50	6.00
% Total vegetation cover	55.00	11.50
% Vegetation understory	16.30	8.00
% Perennial grasses	5.10	6.30
% Tree cover	39.50	12.60
% Total nonliving material	51.40	10.80
% Rock	9.70	7.20
% Bare ground	20.10	9.20
% Litter	36.40	9.70
% Surface gravel	21.60	11.00
% Gravel	11.80	5.40
% Silt	38.20	8.00
% Clay	22.80	13.50
% Slope	13.90	5.80
Species richness (trees not incd.)	14.60	2.81
Soil Value	4.60	0.70
Aspect	198.90	65.50
USLE (K) factor	0.22	0.04
Total soil loss (m^3/ha)	1,255.10	294.50
Annual soil loss (m^3/ha/yr)	15.70	5.70

* When spectral variables were used as dependent variables, other spectral variables were not used as predictors (independent) variables. The reason for this was to avoid biasing the results due to the high degree of multicollinearity existing between the TM spectral channels. Also, only sets of noncorrelated independent variables were used in the multiple regression analysis test.

** All four TM channels were used in Principal Components Analysis to generate a single spectral component. The four channels were alsoused in a second PCA test to generate two principal components. The first component was most correlated with the visible TM channels(Channels 2 and 3) and the second component was most correlatedwith the middle infrared channel (Channel 5). TM channel 4 did notload heavily on either component.

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